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Monitoring of Complex Visual Displays—II. Effects of Visual Load and Response Complexity on Human Vigilance,[1]

JACK A. ADAMS, HERBERT H. STENSON and JOHN M. HUMES, University of Illinois.

A vigilance experiment was performed on the characteristics of visual monitoring behavior in complex tasks like those found in modern semi-automatic systems. The activationist hypothesis, which contends that human alertness is a function of stimulation level, served as framework for the experiment. Under investigation were sources of environmental and response-produced stimulation that might be related to human alertness. A simulated semi-automatic air defense surveillance task was used. Environmental stimulation was manipulated by requiring six or thirty-six visual stimulus sources to be monitored for a 3-hr observation period. Response-produced stimulation was a function of response complexity. No vigilance decrement was found for per cent of signals correctly detected. Response latency declined significantly, but slightly, for groups that had simple response conditions but not for groups with complex response requirements. Results were discussed in terms of issues in operationally defining sources of stimulation for the activationist hypothesis, and the cautions that must be observed in generalizing from the simple tasks of most vigilance experiments to the complex tasks of semi-automatic systems.

INTRODUCTION

The advent of automatic control and computing subsystems in modern semi-automatic man–machine systems has meant changes in response emphasis for the human operator. In older systems, the operator had little assistance from machines in displaying monitoring, controlling, computing and decision making, and his task was often one of relatively high work load where all of these response classes were required in generous amounts. The rise of automatic subsystems has not necessarily eliminated any of these response classes for the operator, but it has shifted their emphasis in two basic ways:

1. There is an increasing requirement on monitoring behavior that demands sustained vigilance, or attention. With digital computers and automatic control devices assuming much of the routine responding, the operator must be alert for signals commanding his assigned response classes that will serve as inputs to the system. The concern for system performance at this time is the relatively long-term monitoring conditions under which human vigilance may deteriorate, rather than short-term effects of spatial and temporal expectancies that have intrigued some investigators.

2. A greater proportion of operator response is involved in decision-making functions than ever before. This does not imply that simpler responding has been eliminated, but only that it occupies a reduced status in the daily job routine. Many simple response classes must be retained at high strength in the operator's repertoire as redundancy elements to enhance system reliability because, when automatic subsystems malfunction, the operator can play the vital role of inserting manual inputs as substitutes for the normally automatic ones. Lusser[19] has emphasized that the tremendous complexity of equipment has created grave problems for system reliability, and Westbrook[27] has been among those developing the view that the human operator as a versatile redundant component can give a significant increment to reliability. Man has other virtues as a system element, but in many ways we can justify him for reliability reasons alone.

[1] This research was supported by Contract AF 19(604)-5705 monitored by the Operational Applications Office, Electronic Systems Division, Air Force Systems Command.

The human operator is not going to be a good decision maker, or a redundant subsystem, if he cannot accurately and speedily detect the signals that command his responses. Thus, the contribution of the human operator to system performance becomes importantly dependent upon his vigilance under conditions of prolonged monitoring when the automatic subsystems are doing most of the work. And, because monitoring activities in semi-automatic systems now occupy a substantial portion of the operator's time, the determiners of monitoring behavior become an important topic for research. Most experiments on vigilance reveal man as a poor monitor by demonstrating decrement in response proficiency as a function of observation time.

The impetus for these experiments that show vigilance decrement primarily came out of World War II problems of monitoring PPI scopes where the operator had to detect the occurrence of a small, transient, raw radar return, and the emphasis on this class of signals has persisted in vigilance research. However, we cannot assume that the results of such experiments are generalizable to the tasks of present and future systems. While not intending to cast doubts on the scientific adequacy of prior studies, the tasks for human operators in semi-automatic systems have new variables that may have new influences on the development of vigilance decrement. There are three prominent classes of new variables:

1. *Symbolic stimuli.* Information from a digital computer is commonly presented as alphanumeric characters and specialized symbols that often will persist for some time on the display, or perhaps persist indefinitely until a response is made to them. They are not the transient, near threshold signals that have dominated most vigilance research so far.

2. *Load.* Conrad[6] uses the term "load" to mean the number of stimulus sources that can present critical signals for response. Rather than watch a single display element like a PPI scope, the monitoring operator must now scan a number of stimulus sources. Any one of the sources may exhibit a critical change for detection and response.

3. *Response complexity.* The increasing emphasis on decision-making responses has been mentioned above.

It is evident that the issue for system design and use is these new operator variables with an unknown influence on monitoring behavior. Frankmann and Adams[8] have pointed out that the occasional vigilance experiment that has used a complex task with multiple stimulus sources has failed to show vigilance decrement, and this is a puzzling finding because of the commonplace decrement found for simple tasks. Studies by Hoffman and Mead,[10] Broadbent,[4] Howland,[11] Jerison and Wallis,[14] Jerison and Wing,[15] and Loeb and Jeantheau[18] all failed to find decrement in tasks where more than one stimulus source was monitored. Adams and Boulter[2] found a very slight decrement but for one measure only. Investigators have most often used tasks which gave them a decrement, and have failed to exploit the scientific understanding that might arise in the study of tasks that do not induce decrement at all.

Findings for complex vigilance tasks may seemingly be at odds with those for simple vigilance tasks, but the inconsistencies are resolved when viewed in terms of the *activationist hypothesis* that relates alertness to the stimulation level of the task. The basis for this hypothesis is the provocative physiological research on the ascending reticular activating system which has been reviewed by Hebb,[9] Lindsley,[17] Malmo,[21] and Samuels,[24] and has been related to the vigilance literature by Frankmann and Adams,[8] Broadbent,[5] and Scott.[25] This hypothesis emphasizes that a stimulus en route to its cortical area not only travels its traditional sensory pathway (cue function) but also travels along collateral pathways through the reticular formation and terminates in diffuse, non-specific cortical firings

(arousal function). Scott[25] has most explicitly documented the implications of stimulus arousal for vigilance, and he has emphasized the performance deterioration that occurs in repetitive tasks with a uniform sensory environment. He concluded that loss of efficiency is a function of sensory uniformity, and the more unchanging the stimuli the sooner deterioration occurs. Furthermore, Scott holds that the human operator undergoes a period of "sensory habituation" to the arousal properties of stimuli. A gradual loss of alertness develops through continued exposure to uniform stimuli. Under conditions of severe isolation over extended periods, more pronounced behavioral changes such as hallucinations appear, as in the well-known McGill studies of sensory deprivation.

The failure of decrement to appear for complex vigilance tasks is consistent with the activationist hypothesis presumably because of the heightened stimulation of the complex display, the increased response-produced stimulation from the head and eye movements of visual scanning, and the added sources of internal stimulation if choice and decision are involved in the responding. An explanation of these findings in terms of a work inhibition construct like Hull's I_R[12] conforms less well because, if anything, the increased response activity in a complex task should produce more, not less, decrement. A similar strain is placed on a work inhibition view for the well-known findings of Deese and Ormond[7] and of Jenkins[13] where vigilance decrement was least when signal rate was the highest. More responses per unit of time bettered performance, not worsened it as work notions would imply. Even the recovery benefits of rest for vigilance decrement that have been found by Mackworth[20] and Adams[1], which seem to fit the work inhibition hypothesis so comfortably, can just as well be explained by the activationist hypothesis in terms of changes in stimulation that accompany the casual rest period administered in psychological experiments.

Perhaps the difficulty with the activationist hypothesis, at this time, is that it explains too much. The core of the hypothesis is stimulation, but the hypothesis is loosely expressed and gives no operational definition of stimulation, either in terms of environmental or response-produced stimuli. The potential explanatory power of the hypothesis is large, but research needs to clarify the operations that define the amount and the variation in environmental and response-produced stimulation that are relevant for human alertness. Until we give explicit definition to the sources of stimulation, and relate them to measures of alertness, we cannot accept or reject this scientific hypothesis or predict vigilance decrement in new tasks.

METHOD

Purpose

The purpose of this experiment was to provide data on the monitoring behavior of the human operator in semi-automatic man–machine systems, and to provide a first approximation of the defining operations for environmental and response-produced stimulation for the activationist hypothesis. On the environmental side, stimulation level was defined by the number of visual stimulus sources to be monitored. Response-produced stimulation was manipulated in terms of response complexity. Three hours of continuous visual monitoring was required in a simulated air defense surveillance task.

Stimulus Display

The subject sat in a sound-treated room, illuminated by broad-band blue lighting, and viewed a phosphorescent screen of 22-in. diam. in the wall of the room, on which the display was rear-projected. Six or thirty-six symbols were the stimulus sources in the projected display.

Figure 1 is an example of the display for six stimulus sources. The subject's task over the three-hour monitoring period was to detect the change of a G to an F and report it with a

simple or complex response by pressing one or more buttons on a panel located by his right hand. The symbol marked F 675 in Fig. 1 is an event to be reported. The critical F signal persisted for 20 sec before reverting to G. The three-hour period was divided into nine 20-min trials for scoring purposes, and the mean intersignal interval on a trial was 280 sec. There were four signals on a 20-min trial and the randomly assigned intersignal intervals were 100, 220, 340 and 460 sec. These four intervals were randomly assigned for each trial.

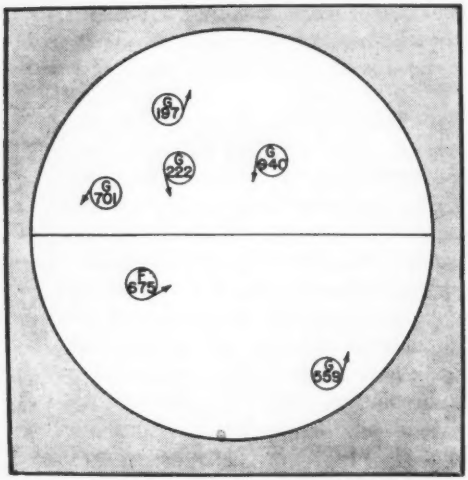

Fig. 1. The vigilance display with a moderate visual load of six symbols. Symbol 675 with the G changed to F for 20 sec is an event to be detected and reported. The display looked the same for thirty-six symbols except that it was visually crowded. (Not drawn to scale.)

The task simulated a semi-automatic air defense system where a computer would periodically display symbolic information about aircraft to the operator. An animated 35 mm strip film simulated a 1000-mile surveillance area, with aircraft programmed for speeds of either 450, 900 or 1800 knots. Once initiated, an aircraft symbol was programmed linearly in the direction indicated by the arrow attached to the symbol and at a rate proportional to one of the three speeds. The three speeds were always equally divided among the symbols on the display. When a symbol reached the edge of the screen it was removed and immediately replaced by another at a different place on the screen, thereby always keeping visual load constant for a subject. The method was to project a frame of film on the phosphorescent screen in front of the subject for 3 sec, and then remove the image for one second with a shutter mechanism—thus allowing the symbols to go into a brief phosphorescent decay state on the screen. During the one-second off-period the next frame was advanced. When the shutter was raised, and a new film frame was presented, a critical change for detection was or was not present. This task then, represented a strip film simulation of a computerized system where the computer drum was periodically read and its data flashed on a display in front of the operator.

Apparatus

A modified DuKane strip film projector, Model 576–39A, was used. Automatic presentation of the film for 3 hr was by a cam-timing device which controlled a solenoid-operated shutter and the film advance mechanism.

The subject responded by pressing a button on a 41-button response panel at his right hand. The experimenter on the outside of the room had a repeater panel of forty-one tell-tale lights that indicated which buttons were pressed. In addition, response latency was measured. A photoelectric cell system activated a timer when a signal first appeared on the screen, and the timer was stopped when the subject pressed any one of the buttons. Between responses the subject kept his hand in a standard rest position. If the subject moved his hand from this control position, a light appeared on the experimenter's panel and the intercom system was used to inform the subject that his hand must be kept in the proper position. This technique was an experimental control for error in response latency measures ascribable to the distance of the hand movement.

Experimental Design

A Lindquist[16] Type III mixed design for analysis of variance was used. Visual load and response complexity were between-group treatments, and trials (observation time) was a within-groups treatment common to all groups. There were two values of visual load, six and thirty-six symbols as stimulus sources, and two values of response complexity, Detection (D) and Evaluation (E). Four independent groups of fifteen subjects each were employed. Each group received one of the four combinations of load and response complexity, and their designations were 6-D, 6-E, 36-D and 36-E. Response complexity was defined in terms of the number of choices involved in evaluating the signal change and reporting it. A subject in the Detection condition merely had to detect the change and press the button labeled F on his response panel. In the Evaluation condition, however, a subject had to detect the signal change and then make a four-choice evaluation of the symbol on the display and indicate his decision by first pressing either button A, B, C or D, and then following it with the buttons for F and the three numbers of the symbol. The subject had to decide whether the symbol whose G had changed to F ended in an odd or an even number, and whether the symbol was above or below the horizontal line across the center of the display. For example, the subject might be required to respond by pressing buttons DF 675.

Each subject was given a three-hour practice session on a day preceding his criterion session. The purpose of the practice session was to provide thorough learning so that changes in the scores of the subsequent criterion session reflected changes in the vigilance state of a subject, not learning effects. To promote learning during the practice session, the subject was given complete knowledge of errors over the intercom system. A different film was used for the practice session than for the criterion session. The visual load and the condition of response complexity was the same in both sessions, but the mean signal rate was 1/min in the practice session and 1/5 min in the criterion session. Analysis of these practice data indicated that the training goal was accomplished because the mean response latency curve for each group was at its asymptote by the end of the practice session.

No knowledge of results was given in the criterion session because this was a source of stimulation outside those of interest for the experiment. A subject's cigarettes, matches, and watch were taken from him before each session.

Subjects

The sixty subjects were male university undergraduate students. They were paid for their participation.

RESULTS

Table 1 shows the per cent of signals correctly detected by each group. The typical vigilance experiment almost always uses per cent correct as the basic performance measure, and ordinarily decrement appears as a function of observation time. In contrast, it will be noted that none of the four groups show a decrement effect during the three-hour period. This finding confirms an earlier one by Adams and Boulter[2] using the same apparatus. Differences in the overall level of per cent correct are seen in Table 1, but they are associated with the level of visual load and response complexity, not trials.

TABLE 1

Per Cent of Signals Receiving Correct Response Over the Three-hour Observation Period

Group	*Blocks of Three Trials*			*Total*
	1–3	4–6	6–9	
6-D	98.9	100.0	98.9	99.3
6-E	93.3	97.2	95.0	95.2
36-D	96.3	96.7	96.7	96.6
36-E	89.7	88.8	88.8	89.1

The failure of per cent correct to change as a function of observation time does not mean that changes in vigilance did not take place.

Our measurement of response latency recognized that deterioration of response speed might occur even though the subject made a correct response. The mean latency for all correct responses by a subject on a trial was used as his basic score for analysis, and a plot of group means is shown in Figure 2. As might be expected, the more demanding search task under high visual load conditions results in Groups 36-D and 36-E performing at a poorer level than Groups 6-D and 6-E with a moderate visual load. Also, the two Evaluation response conditions exhibited poorer performance than

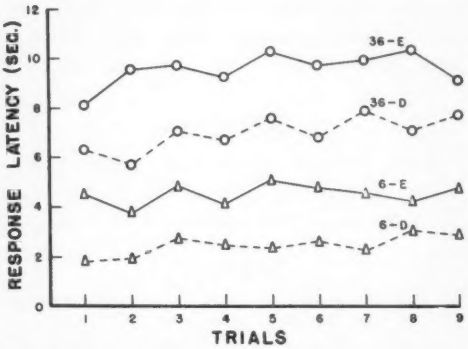

Fig. 2. Mean response latency as a function of trials (3-hr observation time) for each of the four groups.

simple Detection responding. Vigilance decrement in response latency over trials was a slight effect, when it was discernible at all.

An examination of the raw latency data revealed correlations between means and variances, so the Lindquist[16] Type III analysis of variance was performed on log latency values. All main effects of Load, Response Complexity, and Trials were significant at less than the 0.001 level. The Load × Response Complexity interaction was the only interaction term significant at less than the 0.05 level.

Because Trials displayed a significant decremental effect overall, the individual groups were tested for a trials trend, using the combined within-groups error term from the Type III analysis. Groups 6-D and 36-D had a decremental trend with trials that was significant at less than the 0.01 level. The F ratios for Groups 6-E and 36-E were not statistically significant.

DISCUSSION AND CONCLUSIONS

The traditional vigilance measure of per cent correct failed to show decrement over 3 hr when the complex visual task had multiple stimulus sources and the critical signals were non-transient. Whatever differences were found in per cent correct were associated with the overall difficulty of an experimental condition, not observation time. Response efficiency as a function of visual stimulus load is consistent with the work of Conrad[6], and the longer latency for more complex decision responding is a straightforward expectation.

The effects of waning vigilance, as revealed in an increase of response latency over 3 hr, was associated only with the simple Detection response, not the Evaluation decision responding. This same finding emerged in an earlier study by Adams and Boulter[2], and is corroborated here. It appears that response-produced stimulation, at least of a central kind, is significant for alertness states. Lindsley[17] has discussed evidence for cortical firings exerting a descending, or feedback stimulation, on the reticular formation, and this may be the mediational basis of added alerting properties in decision making that is absent in simple detection responding.

The hypothesis associated with visual load as a source of environmental stimulation for attentiveness was not sustained. It was hypothesized that thirty-six stimulus sources would provide a much higher level of environmental stimulation than six sources, and decrement should be less. But decrement was found to be differentially associated with the response complexity variable, not load. There are three likely explanations:

1. The moderate visual load was sufficient stimulation for good alertness, and increasing

it made no further difference. Using this same task and a load of six sources, Adams and Boulter[2] employed the same line of reasoning when they found no difference between a mean signal rate of 1/min and 1/5 min. They hypothesized that the increment in stimulation provided by the more rapid rate made no difference because the inherent stimulation level in the task was already sufficient for high alertness.

2. External, environmental stimulation is far less important for vigilance than response-produced stimulation. Most studies confound these two sources of stimulation and make the laws of alertness difficult to clarify. The provocative vigilance experiment by McFarland, Holway and Hurvich[22] demonstrated that decrement in visual threshold could be eliminated by having the subject stretch or participate in neutral conversation with the experimenter. However, we cannot tell from this study whether the environmental stimulus of the verbal instructions to stretch was most critical, or whether it was changes in the response-produced proprioceptive stimulation of stretching. Similarly, when neutral conversation with the experimenter was the variable, the elimination of vigilance decrement could have been from external stimulation of the experimenter's voice, or from response-produced stimulation of the subject's verbal replies. A similar criticism can be made of a study by McGrath[23] who found that meaningful stimulation such as music increased the level of signal detection. Again it is not clear whether the critical stimulation for alertness is the environmental sound or the response-produced stimulation likely arising from the subject humming and singing to himself. We appear to be on increasingly safe grounds in ascribing high alertness to *some* source of stimulation, but we will not have careful statements of the empirical laws of vigilance until the sources of stimulation are identified and properly weighted as determinants of monitoring behavior.

3. The *amount* of stimulation may be of far less significance for maintaining alertness than the *variety* of stimulation. Increasing the visual load from six to thirty-six increases the amount, but it may not increase the variety of environmental stimuli. Evidence for this possibility can be found in McGrath's[23] experiment where visual detection level was increased by varied auditory stimulation such as music, but not white noise. Variety would be one dimension of difference for these two classes of stimulation. Sharpless and Jasper[26] found that habituation of the arousal reaction in the cat to auditory stimuli was eliminated simply by changing the frequency of tones, or by presenting a novel arrangement of familiar auditory stimuli. Similarly, the effectiveness of response complexity in the experiment reported here may have been because the four-choice decision usually involved a different symbol and decision each time, and this gave variety in response-produced stimulation. An experiment by Whittenburg, Ross, and Andrews[28] demonstrated that simply increasing the amount of response-produced stimulation was insufficient to deter the development of decrement with the Mackworth Clock Test[20]. A group that pressed one key each time the clock had advanced, and another key when the critical double jump of the hand was detected, had no better detection performance than the group which pressed a key only when a critical signal appeared. This would seem to be an instance of increasing the amount of stimulation, and their experiment suggests that mere amount may be of doubtful value for maintaining alertness. All of these findings suggest that variety in stimulation may be critical.

With all of these definitional problems for the activationist hypothesis, it is evident that much research remains to be done. Increasingly, vigilance findings are emerging which cannot be explained by fatigue-like

hypotheses. Our present finding of less decrement for four-choice decision responses cannot be easily explained with a concept like Hull's I_R[12]. While no one at present is suggesting that views of effector fatigue are inappropriate explanations for all decremental phenomena and should be displaced by the activationist hypothesis, there are findings such as those reported here where work decrement views appear to be strained in their application. The possibilities of a two-factor theory of fatigue-like states cannot be discounted, but it is speculative to discuss it further until the activationist hypothesis is given sharper focus.

Implications for Semi-automatic Man-machine Systems

It is commonly heard that the human operator in complex semi-automatic systems will be confronted with serious vigilance problems because automatic controls and computer subsystems are doing most of the responding, and deterioration in his monitoring behavior will degrade performance of the overall system. Such judgments at worst are based on casual observations, and at best on tenuous generalizations from research on simple vigilance tasks that have their roots in World War II systems. Many times the state of our scientific knowledge in engineering psychology leaves no choice but to generalize from experiments on simple tasks to the behavioral demands of complex tasks that are common in contemporary and future semi-automatic systems. Generalizations from simple tasks to complex ones may be good or bad, depending on whether a complex task has new variables or interactions not present in simpler situations. Adams and Xhignesse[3] (p. 391) have pointed out that the adequacy of generalizations from simple to complex tasks is an empirical matter for research, and the experiment reported here, as well as others on complex tasks with multiple sources, show that generalizations from simple to complex vigilance tasks cannot be made uncritically. Our experiment does not support the gloomy predictions about man as a poor monitor in semi-automatic systems. We found no decrement in per cent of signals correctly detected, and the small decrement in response latency that did occur for two out of the four groups probably would not be considered operationally significant for most systems. There is something about complex tasks that is favorable for human vigilance.

The activationist hypothesis is favored for explaining vigilance data from complex tasks, but we have indicated that the hypothesis has many loose ends. As research better delineates the activationist hypothesis, we may eventually develop the capabilities to unify the findings for simple and complex vigilance tasks, to predict monitoring behavior for different types of tasks, and to design tasks that will keep human alertness high for relatively long periods. Designing for vigilance may require that the human operator be given certain types and number of stimulus sources, or that the distribution of responses between man and machines allocate to man the number and type of responses that will keep him alert even though machines may be able to handle them with ease. There may be more to optimizing system performance than simply assigning a response item to a subsystem that is unoccupied at the moment.

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Man–Machine Steering Dynamics

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A human factors analysis of the vehicle steering problem is presented, in which the perceptual variables involved are identified and the wide variation in human gain required for stable steering at all speeds is demonstrated. A velocity-modulated steering system is proposed as a solution to this problem, and the effects of such a system upon steering behavior are examined.

INTRODUCTION

With the advent of a vastly improved national and state highway system and with increased horsepower available from Detroit, there has been rising pressure for higher driving speeds. In many areas, speed limits recently have been increased by 5 to 10 m.p.h., and it has been almost a decade since automobile speedometers used 100 m.p.h. as maximum indicated speed (120 m.p.h. is prevalent today, with a few instances of 140 m.p.h.).

In contrast to this press toward higher speed there has also been a rising amount of low-speed or "city" driving due in part to the increasing numbers of mobile suburbanites. The popularity of power steering with harassed mothers attests to the amount of "stop–park–shop–go" driving which they do.

We have, then, a need for safe, stable driving at high speeds coupled with the simultaneous requirement for a large mechanical advantage at low and near-zero speeds for city driving and parking. But these are conflicting requirements for the linear steering systems in today's automobiles: sufficient mechanical advantage for parking results in excessive steering sensitivity at high speeds, with a tendency to "hunt" laterally in a roadway lane, while the lower sensitivity appropriate for high speeds results in too low a mechanical advantage for parking ease. Attempts to find a reasonable linear compromise between these two extremes must fail, simply because the extent to which one requirement is met by a given steering system is exactly the extent to which the other is abrogated.

However, with all due respect to the preceding discussion, it would appear that people are able to drive today's automobiles fairly well. Our suspicion, then, is that a driver learns to compensate for the changing characteristics of his steering system as a function of speed and that the degree of compensation required bears some relation to steering stability at high speeds. Our concern is with the form of this compensation and, in essence, with the nature of the steering task itself: How, indeed, does an automobile driver achieve stable steering? What are his perceptual inputs and what relation do they bear to his response with the steering wheel? And finally, how do the physical characteristics of the vehicle itself, such as wheelbase and steering gain, affect the demands which the vehicle dynamics make upon the driver at varying speeds?

The example of the automobile is used only because it is most familiar to a broad audience. These questions, in addition to the basic concepts covered in this paper, are equally applicable to any type of "steerable" vehicle including aircraft, boats, tanks etc.

The essential thought underlying this paper is that the human operator of a vehicle steering system must act as an element in a closed-loop servo system. The functions of this human element appear to be as follows:

1. To select a reference (point, line, angle, curve etc.) from which to determine the vehicle misalignment or deviation (i.e. error).
2. To detect such errors.
3. To establish an error criterion.
4. To respond to the detected error (via the steering wheel) in such a manner as to maintain the vehicle within the established criterion limits throughout the duration of the steering task.

These are complex functions for a servo element of any type to perform. With this consideration in mind, it is a natural consequence to seek ways in which the human's steering task could be made safer and simpler.

ANALYSIS

In order to gain insight into the way in which the human functions as a servo element in a vehicle steering system, the following simplified analysis of automobile steering geometry is presented.

Figure 1 illustrates the geometry of the vehicle steering problem for single lane driving on a

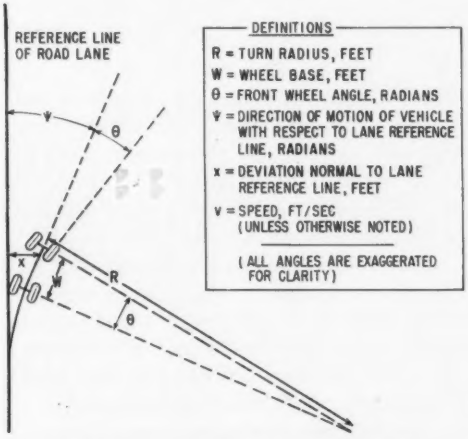
REFERENCE LINE
OF ROAD LANE
DEFINITIONS
R = TURN RADIUS, FEET
W = WHEEL BASE, FEET
θ = FRONT WHEEL ANGLE, RADIANS
ψ = DIRECTION OF MOTION OF VEHICLE WITH RESPECT TO LANE REFERENCE LINE, RADIANS
x = DEVIATION NORMAL TO LANE REFERENCE LINE, FEET
v = SPEED, FT/SEC (UNLESS OTHERWISE NOTED)
(ALL ANGLES ARE EXAGGERATED FOR CLARITY)
ψ
θ
x
W
R
θ

Fig. 1. Simplified vehicle steering geometry.

straight road. Certain simplifying assumptions are used for convenience:

(a) $\theta \leqslant 10°$
(b) $\sin\theta = \theta$
(c) $\psi \leqslant 10°$
(d) $\sin\psi = \psi$
(e) v = constant
(f) Effects of suspensions, cross wind, wheels, tyres, road crown, skid or slip, inertia etc., are neglected.

Under these assumptions, the following simple and fundamental equations can be derived from the relationships illustrated in Fig. 1:

$$R = \frac{W}{\theta} \tag{1}$$

$$\dot{\psi} = \frac{v}{R} \tag{2}$$

$$\dot{x} = v\psi \tag{3}$$

Where:

R = turn radius (ft)
W = wheel base (ft)
θ = front wheel angle (radians)
ψ = direction of motion of vehicle with respect to lane reference line (radians)
v = speed (ft/s)
$\dot{x} = dx/dt$
$\dot{\psi} = d\psi/dt$

Substituting (1) in (2) results in:

$$\dot{\psi} = \frac{v\theta}{W} \tag{4}$$

Taking the derivative of (3) with respect to time (holding v constant) results in:

$$\ddot{x} = v\dot{\psi} \tag{5}$$

Substituting (3) and (4) in (5) results in:

$$\ddot{x} = \frac{v^2\theta}{W} \tag{6}$$

Equation (6) relates the vehicle's lateral acceleration with respect to the road lane reference line to speed, wheelbase, and front wheel angle and represents a simplified model of the system dynamics at constant speed without the human operator.

Although several possible avenues of approach may be taken in analyzing human operation in the steering loop, a good starting place is the perceived information upon which the driver might base his continuous judgment concerning steering.

The human perceptual problem is indicated more clearly in Fig. 2 which shows that there are at least six perceptual variables (the three shown plus their rates of change) with which the man might have to deal on an instantaneous and continuing basis.

From Fig. 2 we can infer that, for small angles ($\psi \leq 10°$),

$$x = D\psi \tag{7}$$

Differentiating this once, we obtain:

$$\dot{x} = \dot{D}\psi + \dot{\psi}D \tag{8}$$

Solving this expression for $\dot{\psi}$ and substituting for $\dot{x}$ from Equation (3), we get:

$$\dot{\psi} = \psi\frac{v-\dot{D}}{D} \tag{9}$$

Setting (4) and (8) equal, we obtain:

$$\frac{v\theta}{W} = \psi\frac{v-\dot{D}}{D} \tag{10}$$

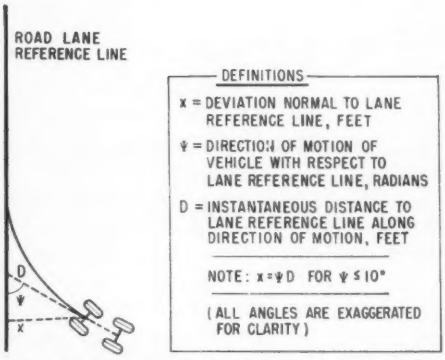
ROAD LANE
REFERENCE LINE
DEFINITIONS
x = DEVIATION NORMAL TO LANE REFERENCE LINE, FEET
ψ = DIRECTION OF MOTION OF VEHICLE WITH RESPECT TO LANE REFERENCE LINE, RADIANS
D = INSTANTANEOUS DISTANCE TO LANE REFERENCE LINE ALONG DIRECTION OF MOTION, FEET
NOTE: x=ψD FOR ψ ≤ 10°
(ALL ANGLES ARE EXAGGERATED FOR CLARITY)
D
ψ
x

Fig. 2. Perceptual variables in vehicle steering.

Solving (10) for θ, we obtain:

$$\theta = \psi\frac{W}{v}\frac{v-\dot{D}}{D} \tag{11}$$

If as in most standard automobiles the steering system is "reversible"[1] then the nose wheel displacement θ is proportional to the force F applied by the driver to the steering wheel, *viz.*:

$$\theta = kF \tag{12}$$

[1] In the "irreversible case" (e.g. certain power-steering systems) the displacement θ may instead be proportional to the angle α through which the steering wheel is operated, with the disadvantage that there is no force feedback to the driver. For a discussion of why the force-displacement concept is more desirable, see Birmingham and Taylor.[1]

Equation (11) can be rewritten as

$$F = \frac{\psi}{k}\frac{W}{v}\frac{v-\dot{D}}{D} \tag{13}$$

Thus the force output required of the driver is seen to be a complex function of a number of quantities, including several variables.

Up to this point we have made no assumptions concerning the primacy of one or another perceptual input, so that the results are perfectly general. If we now assume that the variable ψ is the driver's primary visual cue in steering and F his primary output, then the function F/ψ represents a simple linear approximation to his transfer function. From Equation (13), we obtain:

$$\frac{F}{\psi} = \frac{1}{k}\times\frac{W}{v}\times\frac{v-\dot{D}}{D} \tag{14}$$

This statement represents the assumption that the perceptual variable x (lateral distance from reference line) does not play an important part in the steering task. It does not, however, tell us anything about the variable D other than that it must be taken into account by the driver.

Some observations on steering behavior are in order at this point. Most drivers are probably aware of the fact that they tend to look farther ahead at high speeds than at low speeds. This is a logical outgrowth of the fact that given a particular control task a human operator is characterized by a more or less constant response time so that his anticipation requirements dictate that he "look ahead" at least a distance equal to response time divided by speed (this is then the distance traveled during the interval of one response time). It may be possible to quantify the relationship experimentally by means of precise eye movement studies to determine fixation point as a function of vehicle speed.

In line with these observations and in the absence of definitive data, then, let us make two further extremely important assumptions: (1) that the driver looks a distance ahead, d, which is directly proportional to speed viz. $d = \tau v$, where τ is his mean response time in seconds; and (2) that he continually attempts to maintain

the condition $D = d$ by adjusting ψ via the medium of the steering wheel. The latter assumption can best be illustrated by assuming that the driver extends an imaginary line of length $d = \tau v$ ahead of his vehicle and pointed in the direction of motion, and attempts to keep the far end of this imaginary line exactly on the reference line of the road lane by his steering behavior. We may then introduce the resulting relationship representing these two assumptions:

$$D = \tau v \tag{15}$$

Now $\dot{D} = 0$ since in the present analysis v is also a constant (from a previous assumption). With these relationships in mind we can rewrite Equation (14) as follows:

$$\frac{F}{\psi} = \frac{W}{kD} = \frac{W}{\tau k v} \tag{16}$$

The significance of Equation (16) will be discussed later.

Next, let us suppose that x (i.e. lateral deviation from reference line) is the driver's primary visual input instead of ψ. From Equation (16) we see that:

$$F = \frac{\psi}{k} \times \frac{W}{D} \tag{17}$$

But $\psi = x/D$ (from Equation (7)). Substituting this in Equation (17) we obtain:

$$F = \frac{x}{k} \times \frac{W}{D^2} \tag{18}$$

As in Equation (15), we assume again that $D = \tau v$. Substituting this in Equation (18) and solving for (F/x), we obtain the desired result:

$$\frac{F}{x} = \frac{W}{k\tau^2 v^2} \tag{19}$$

It is instructive to assess the relative meanings of Equations (16) and (19) as possible human transfer functions. First, we see that both are dependent only upon three constants W (wheelbase), v (speed) and τ (response time). Second, we can determine whether stable steering operation is possible in either case by solving both Equations (16) and (19) for F, then substituting successively in Equations (12) and (6).

From (16), $F = (W\psi/k\tau v)$. Substituting this in (12) and (6) we obtain $\ddot{x} = v\psi/\tau$. But $\psi = x/D$ from Equation (7); therefore:

$$\ddot{x} = \frac{vx}{\tau D} \tag{20}$$

Again applying the assumption of Equation (15), and substituting for D in (20), we obtain:

$$\ddot{x} = x/\tau^2 \tag{21}$$

The well-known solution to Equation (21) is:

$$x = x_0 e^{-t/\tau} \tag{22}$$

This means that if the driver exhibits the transfer function defined in Equation (14) and uses ψ as his primary perceptual input, his vehicle will always approach the lane reference line in an exponential manner for any given displacement x_0 (the constant $1/\tau$ represents the decay rate of the resulting exponential).

Now let us look at the second possibility. Equation (19) represents the case where the driver uses x as his primary perceptual input. Substituting (19) and (12) in (6), we obtain directly, Equation (21) again. So it is evident that both methods of perceiving apparently lead to stable operation in the vehicle steering task. How then do they differ? To illustrate the difference graphically, both gain functions are plotted in Fig. 3 for $\tau = 0.5$ and $W = 10$ ft.

It is clearly evident that the driver's transfer gain must vary over a wide range to handle different vehicle speeds: in the one case, his gain must be inversely proportional to *speed*, while in the other case it must be inversely proportional to the *square of speed*. The driver's transfer gain in either case is seen to be independent of time and/or frequency and may be characterized quite simply as a *velocity-modulated gain*.

It is quite possible that, in general, the driver may include components of both transfer functions. For instance, his output might be characterized as follows:

$$F = c_1 \times \frac{Wx}{\tau^2 v^2} + c_2 \times \frac{W\psi}{\tau v} \tag{23}$$

where c_1 and c_2 represent the relative proportions of each function being utilized by the driver at any given time. Indeed, it is possible that these relative proportions may vary with learning, with time, or even with speed.

However, it appears more reasonable to assume that, since transfer gain variation with the square of speed is the more difficult task, requiring greatest sensitivity and largest variation, the driver will eventually learn or will

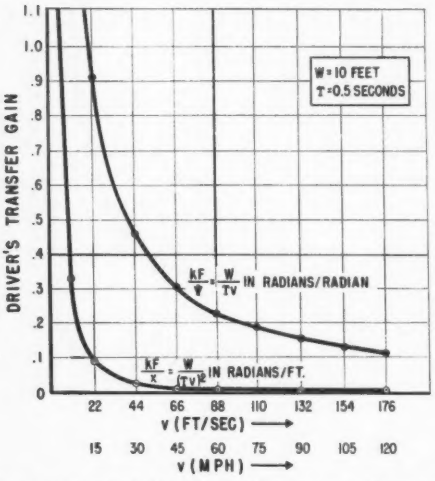

Fig. 3. Required driver's transfer gain as a function of vehicle speed for two different assumptions about perceptual input.

prefer to steer the vehicle using only relative heading (ψ) and distance to lane reference line (D). The considerable weight of opinion in favor of this assumption is summarized by Gibson[4] as follows: "The behavior involved in steering an automobile, for instance, has usually been misunderstood. It is less a matter of *aligning the car with* the road than it is a matter of *keeping the focus of expansion*[2] *in the direction one must go.*"

That a changing gain as a function of speed is required of the driver is not a new observation; this requirement has been recognized, at least implicitly, in connection with the steering of all types of vehicles (see the previous discussion of "distance ahead"). Nonetheless, the extent of the variation in required gain as indicated in Fig. 3 is rather startling. It derives from the fact that steering effectiveness must be maintained throughout a wide range of speeds.

Taken together, these factors indicate a rather complex steering task. As highways have improved and speed limits increased, the inadequacies of linear steering systems with respect to the driver's over-all steering task have become increasingly apparent. If for example a steering gain is selected for best operation at 60 m.p.h. the gain will be found much too low for city driving and parking. On the other hand, if a gain is selected for optimal driving and parking ease, steering at cruising speeds will be found much too sensitive and will often force an undesirable or unsafe change in steering habits (e.g. grasping the steering wheel at the bottom instead of at either side). Thus a steering system design is indicated which minimizes the required variations in driver gain as a function of speed.

PROPOSED SOLUTION

It is proposed that such a design be attempted, based upon known facts and principles of human performance in a servo loop.

It appears desirable from a human factors standpoint for an operator in a servo loop to maintain a high, fixed gain and act as a simple amplifier. Experimental evidence indicates that such operations will result in least variability and greatest accuracy in performance.[1-3, 5]

Translating this statement into terms of the present problem, it means that a given steering wheel torque should always result in the same rate of change of the vehicle's direction of

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[2] The "focus of expansion" in the visual field always represents the direction of motion of the observer. In steering on a straight roadway, relative angular motion of the vehicle with respect to a lane reference line is designated simply as the angle ψ formed by the intersection of the lane reference line with a line extended from the driver to his "focus of expansion," as shown in Fig. 2. In the absence of wind, skid or creep, this line is approximately coincident with the centerline of the vehicle as shown in Fig. 1. Nevertheless, the foregoing analysis is perfectly valid in the presence of a steady cross wind or road crown.

motion ($\dot{\psi}$), regardless of speed (refer back to Equation (4)). In order for this to occur, the steering system must be so designed that the front wheel angle (θ) is made directly proportional to the product of applied steering wheel torque (F) and wheel base (W) and inversely proportional to speed (v) viz.

$$\theta = kF\frac{W}{v} \tag{24}$$

where k is the constant of proportionality as in (12). Equation (24) specifies the operation of a *velocity-modulated steering system*. To see whether

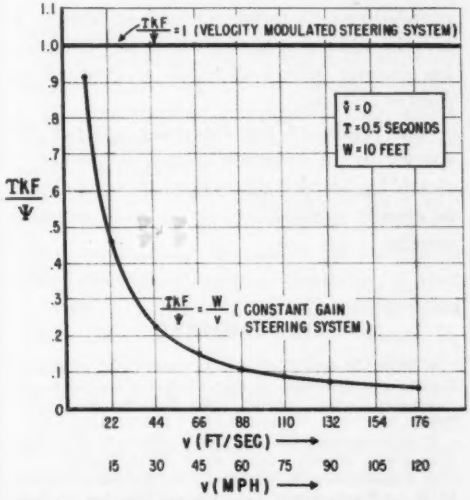

Fig. 4. Required driver's transfer gain as a function of vehicle speed for conventional vs. proposed steering systems.

this mechanization has the desired effect, first substitute (24) in (11). This results in

$$F = \frac{\psi}{k} \times \frac{v - \dot{D}}{D} \tag{25}$$

The contrast between (25) and (13) is evident in that the dependency upon wheel base and inverse speed has been eliminated.

Next substitute (15) in (25) to obtain

$$F = \frac{\psi}{\tau k}\left(1 - \frac{\tau \dot{v}}{v}\right) \tag{26}$$

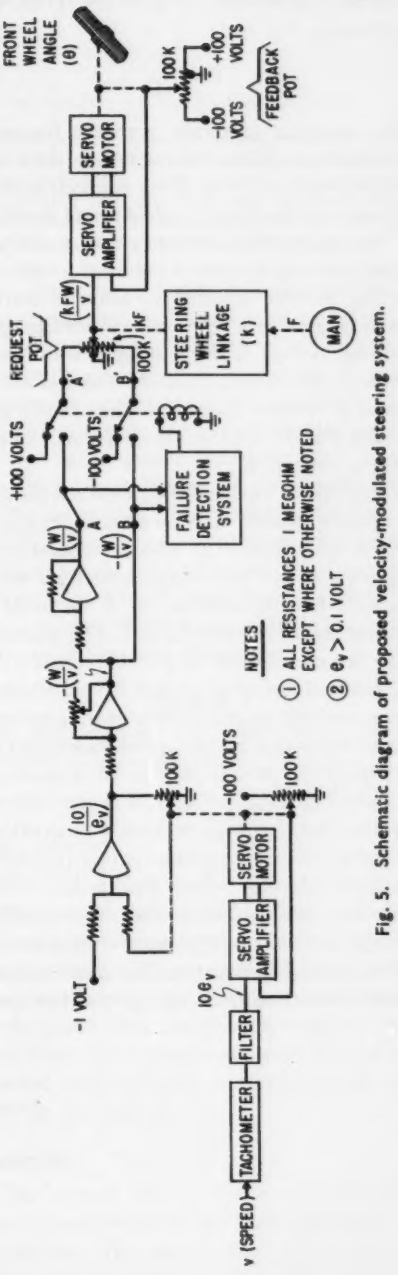

Fig. 5. Schematic diagram of proposed velocity-modulated steering system.

For the assumption of constant speed, (26) reduces to

$$F = \frac{\psi}{\tau k} \tag{27}$$

This equation says that, with the foregoing mechanization of the steering system, the torque output required of the driver is simply proportional to the perceived angle ψ for all speeds.

The comparison between existing and proposed steering systems is indicated graphically in Fig. 4. The required variation in driver's steering gain in a conventional constant-gain steering system falls off sharply with speed, while in the proposed *velocity-modulated steering system* it remains constant. The specific gain level is fixed by appropriate selection of a value for the constant k.

The type of mechanization required for such a steering system is shown schematically in Fig. 5. Introduction of *velocity-modulated* steering requires that the voltage applied across the Request Potentiometer at A'–B' be made an inverse linear function of speed. This scheme is only one of a number of possible schemes, the particular choice of which will depend primarily upon available types of power steering systems, the selection of a reliable speed sensor, and the desirability of introducing fail-safe features.

Referring back to Fig. 5, it is seen that the steering signal voltage is directly proportional to the applied steering wheel torque (F) (which produces steering wheel deflection); vehicle wheelbase (W) and a constant of proportionality (k); and inversely proportional to speed (v); all as required by Equation (24). Such a scheme would indeed result in high gain at low speed city driving and parking, and in low gain at high speeds where over-control might be critical.

An additional important advantage is that, through proper choice of the gain constant k, the lateral acceleration on the vehicle due to steering can be operationally limited to some nominal amount to minimize skidding on bad road surfaces, while at the same time allowing the driver to override this limit in certain situations where a skid might be the lesser of two evils.

Finally, the proposed *velocity-modulated steering system* concept retains the safety feature of requiring that the driver look ahead a distance proportional to speed, without imposing on him the additional burden of varying his steering transfer gain with speed as required by present systems.

The results of the foregoing analysis are specific to the automobile case. However, it should be clear that the method of approach will be equally applicable to any type of steerable vehicle.

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The Effects of Cockpit Vertical Accelerations on a Simple Piloted Tracking Task

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This report presents the results of an experimental simulation study of the effects of vertical accelerations on the ability of pilots to track a simple, one dimensional random signal on the "Pilot Operated Dynamic Flight Simulator" of the Columbus Division of NAA. It was concluded that pilots could track significantly better with simple aircraft response motion cues. However, when gusts and turbulence were added to the cockpit motion, pilot performance was significantly degraded.

PROBLEM

This study was concerned with the effects of vibratory, linear, vertical accelerations on tracking errors during a one dimensional, pitch tracking task. Cockpit vertical aceelerations on a pilot were simulated during a closed loop tracking task such as encountered during I. L. S. final approach, formation flying, terrain clearance flight, and the attack phase of all weather interceptors.

There is a current controversy being waged concerning the value of motion in simulators. When considering the merits of motion in either research or training simulators, it must be kept in mind that only the acceleration components of motion can be sensed by humans. Velocity can only be sensed indirectly by cues other than the physical forces.

A distinction must be made between linear and angular accelerations. Most closed loop training simulators have been concerned with angular accelerations while most linear acceleration has been conducted on centrifuges where acceleration was constant and not affected by the control movement of the tracking task. The recent work on the Johnsville centrifuge and on the Ames simulators are notable additions to closed loop accelerations studies.

METHOD

Apparatus

The simulator used was "The Pilot Operated Dynamic Flight Simulator" of the Columbus, Ohio Division of North American Aviation. The cockpit of the simulator is mounted on 12-ft vertical rails and moves up and down the rails in response to stick movement. Control actions are programmed through the analog computer, which represents particular aircraft control and response dynamics. (Fig. 1 is a simplified block diagram of the simulator.)

The system has a flat frequency response at 3.5 "G's" up to 3 c.p.s. with a maximum rate of 12 ft per sec for ± 5 ft of excursion. The system can go to 10 c/s with second order attenuation characteristics above 3 c.p.s. (Table I is a compilation of simulator capabilities.)

TABLE I

Max. Acceleration	$+5g$ to $-3g$
Frequency Response	Flat to $3\frac{1}{2}$ c.p.s. Attenuated $3\frac{1}{2}$ to 10 c.p.s.
Max. Velocity	12 ft per sec
Max Travel	12 ft

The room in which the simulator is located was darkened during operation and the cockpit internal ambient light was set very high so that no external visual cues of motion were available to the pilots. The power equipment emitted a very loud, high pitched and steady tone, which masked auditory cues of motion from the driving mechanism.

Controls

The aircraft and control system dynamics were representative of the June 1960 B-70 configuration. The control stick was a conventional aircraft center joy stick. Two inches of

[1] Currently with Hughes Aircraft Company, Culver City, California.

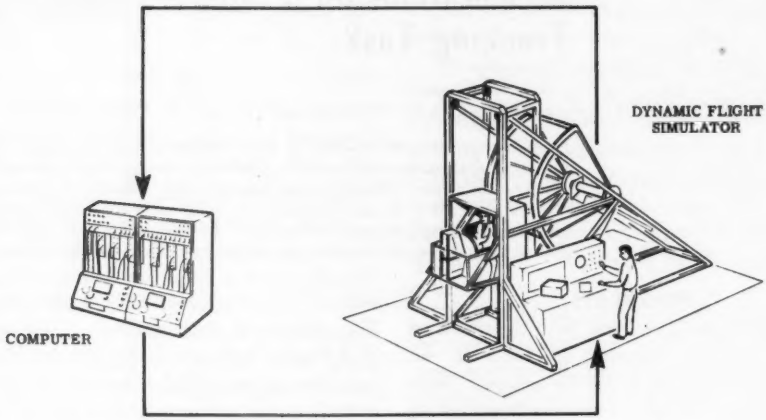

Fig. 1. Simplified block diagram of pilot-operated dynamic flight simulator.

stick travel required 12 lb of force and produced a response of one vertical "G" and 2° per sec of pitch rate.

Displays

The displays consisted of a 5-in. cathode ray tube, an aircraft "G" meter, and a green light that was illuminated when pitch errors were less than $\pm\frac{1}{2}°$. The scope had a center null position etched on the scope face. One degree of pitch error was presented as a 2-cm displacement from center. The error line was approximately 3 in. long.

Task

The task was a compensatory tracking task of aircraft pitch attitude. The dependent variable was r.m.s. error in pitch attitude on trial runs of 3 min each.

Procedure

The experimental design was a balanced, factorial design with five independent variables. These independent variables and their treatment levels were:

1. Motion (four levels)
   (1) Static or no motion.
   (2) Aircraft response motion only.
   (3) Aircraft response plus a low turbulence level. A random gust input with an r.m.s. value of 2 ft per sec was used.
   (4) Aircraft response plus a high turbulence level. The r.m.s. value of the gusts was 4 ft per sec.

2. Frequency of the command signal (3 levels). The frequency component of the command signal was composed of three superimposed sine waves for each frequency level.

	Frequency level (c.p.s.)		
	Low	*Medium*	*High*
Sine waves superimposed to yield frequency component of command signal	0.008	0.016	0.032
	0.027	0.053	0.106
	0.040	0.080	0.159

3. Amplitude of the command signal (three levels). The amplitude was measured in terms of an angular deviation from zero attitude or straight and level flight. The distribution of command deviations was essentially Gaussian about zero but truncated at peak values as follows:

	Peak value
High amplitude	4.5°
Medium amplitude	3.0°
Low amplitude	1.5°

4. Replications (two levels) approximately one week apart.

5. Subjects (four levels) were four highly experienced company test pilots. The subjects were given pre-test practice sessions over the range of test conditions to minimize learning effects.

The order of presentation of frequency, amplitude and motion levels was counterbalanced between pilots and between-pilots-between-replications.

RESULTS

An *a priori* decision was made to transform the r.m.s. error scores to logs before performing the analyses of variance. This transformation was made to normalize the positively skewed distribution of error scores typically found with r.m.s. error scores. A random statistical model was assumed with all interactions present. Preliminary tests for pooling of higher order interaction effects were made at the 0.25 level of significance. After pooling of non-significant interaction terms, the model simplified to:

$$E(X_{ijklm}) = (f)[\mu \ldots + \alpha_i + \beta_j + \gamma_k + \delta_l + \zeta_m + \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \alpha\zeta_{im} + \beta\gamma_{jk} + \beta\delta_{jl} + \beta\zeta_{jm} + \gamma\delta_{kl} + \gamma\zeta_{km} + \delta\zeta_{lm} + \alpha\beta\delta_{ijl} + \alpha\gamma\delta_{ikl} + \alpha\gamma\zeta_{ikm} + \alpha\delta\zeta_{ilm} + \gamma\delta\zeta_{klm} + \alpha\gamma\delta\zeta_{iklm} + \text{error}_{pooled}]$$

where:

α_i = the i^{th} level of variable A (Pilots)

β_j = the j^{th} level of variable B (Motion)

TABLE II

Analysis of Variance: Log Transformations of r.m.s. Pitch Errors

Variance source $n=1$	*SS*	*d.f.*	*MS*	*F*
Pilots (A)	8.16	3	2.72	0.77
Motion (B)	21.95	3	7.32	20.39†
Amplitude (C)	69.42	2	34.71	4.32*
Frequency (D)	140.26	2	70.13	7.31†
Replications (E)	0.87	1	0.87	0.51
AB	1.71	9	0.19	1.27
AC	1.75	6	0.29	0.72
AD	8.77	6	1.46	1.22
AE	11.23	3	3.74	3.23†
BC	0.31	6	0.05	0.36
BD	0.64	6	0.11	0.73
BE	0.10	3	0.03	0.21
CD	30.03	4	7.58	13.28†
CE	0.67	2	0.34	1.73
DE	1.10	2	0.55	0.76
ADE	5.58	6	0.93	3.58*
ACDE	3.13	12	0.26	1.86*
Non-significant Interactions		37		
Pooled error	24.03	171	0.14	
TOTAL		287		

* Significant at the 0.05 level.
† Significant at the 0.01 level.

γ_k = the k^{th} level of variable C (Amplitude of command signal)

δ_l = the l^{th} level of variable D (Frequency of command signal)

ζ_m = the m^{th} level of variable E (Replications)

$\mu \ldots$ = The general mean of the population

the F′ form. The degrees of freedom for the F distribution were approximated by using the procedure suggested by Satterthwaite[7].

The analysis of variance summary is contained in Table II. The main effects for motion were significant at the 0.01 level. The effects of motion on tracking errors described a "J" shaped function as degree of cockpit motion increased as can be seen in Fig. 2. This was

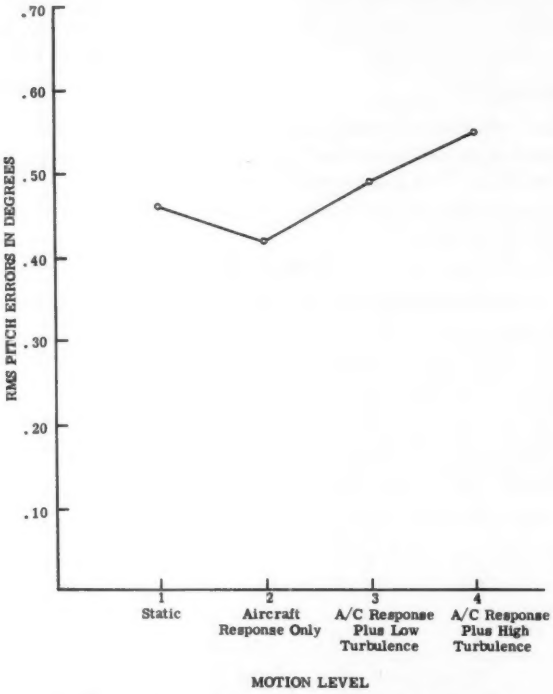

Fig. 2. Effects of increased motion on tracking errors.

$E(X_{ijklm})$ = expected value of the observation in the $ijklm^{th}$ cell of the experiment.

Expected mean squares were derived for each variance source according to the procedure suggested by Bennet and Franklin[1]. The random model necessitated the use of composite or quasi-F ratios and in this case they were of

similar to the result obtained by Brown, Johnson and Mungall[2]. They found that the introduction of linear accelerations into simulator cockpit motion enhanced tracking ability. The results of this study replicated their observations and in addition demonstrated that if motion, which is extraneous to control movement, is fed into cockpit motion, tracking performance will be significantly degraded and to

a much larger extent than control-related motion enhances tracking performance.

The main effects for amplitude and for frequency were significant at the 0.05 and 0.01 level respectively. The trend was in the anticipated direction with errors increasing exponentially with increases in either amplitude or frequency of command signals.

The main effects for pilots and for replications were not significant. The pilots were from a very selected group and the ability range was quite restricted. The task was simple and pre-test experience nullified any between-pilot effects or any between replications effects.

TABLE III

R.M.S. Pitch Error: Means for Main Effects*

Variable	1	2	3	4
Pilots (A)	0.45	0.46	0.47	0.53
Motion (B)	0.46	0.42	0.49	0.55
Amplitude (C)	0.36	0.46	0.61	
Frequency (D)	0.35	0.41	0.67	
Replications (E)	0.48	0.47		

* Means not underlined by the same line are significantly different at the 0.05 level.

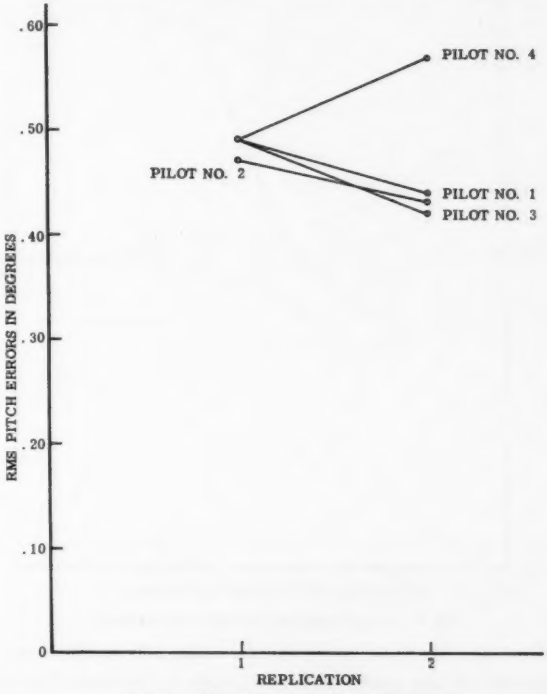

Fig. 3. Pilots by replications interaction.

Table III contains the individual means for main effects. Individual significance comparisons were made using the procedure developed by Duncan.[3] Significance test were made at the 0.05 level.

The pilots by replications interaction was significant at the 0.01 level. This between-pilots-between-trails effect was probably a function of both learning and monotony. The task was easy and one pilot decreased slightly in average performance on the replication trials, while the other pilots increased in performance probably due to learning effects. In short, pilots displayed differential performance

over time on this task. The plot of the pilot by replications interaction appears in Fig. 3.

The amplitude by frequency interaction was significant well beyond the 0.01 level. This large interaction is a clear demonstration that the effects of these two variables on task difficulty is non-additive. Since this was a compensatory tracking task amplitude of deviations were unknown to the pilots and they were tracking the combined effects of amplitude and frequency, or the rate of input excursions. The amplitude by frequency interaction is plotted in Fig. 4. As can be seen, errors increase drastically at the high frequency-high amplitude task conditions.

The pilots by frequency by replications interaction was significant at the 0.05 level. The pilots by frequency by replications interaction can only be described as the pilots adjusting differently to frequency of the command signal over time.

The pilots by amplitude by frequency by replications interaction was significant at the 0.05 level. This interaction is also uninterpretable and can only be described again as differential adjustment by pilots to amplitude and frequency over time. It would be highly desirable to replicate this study to determine if these higher order interaction effects are stable or if they are merely artifacts of this particular test.

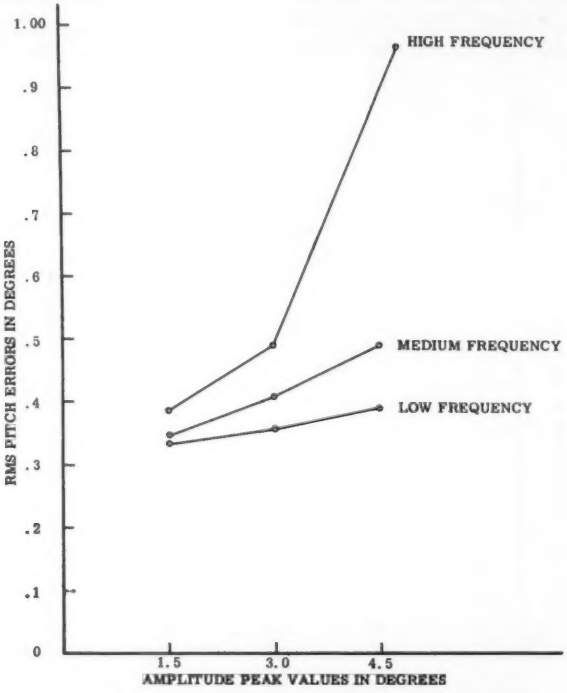

Fig. 4. Amplitude by frequency interaction.

DISCUSSION

The tracking task in this study was a simple one-dimensional task with relatively small amplitude and frequency excursions of the command signal. Fig. 5 is a plot of the effects of

motion for each frequency level. It can be seen that as the tracking task becomes more difficult the effects of motion become more pronounced. The low-frequency, low-amplitude tracking tasks were so mild that the cockpit hardly moved and the motion at the easier

No data were analyzed in this study concerning the frequency amplitude, or duration of excursions beyond a tolerance band of the desired safe flight path and g loading limits. It is suggested that future research include criteria in these forms.

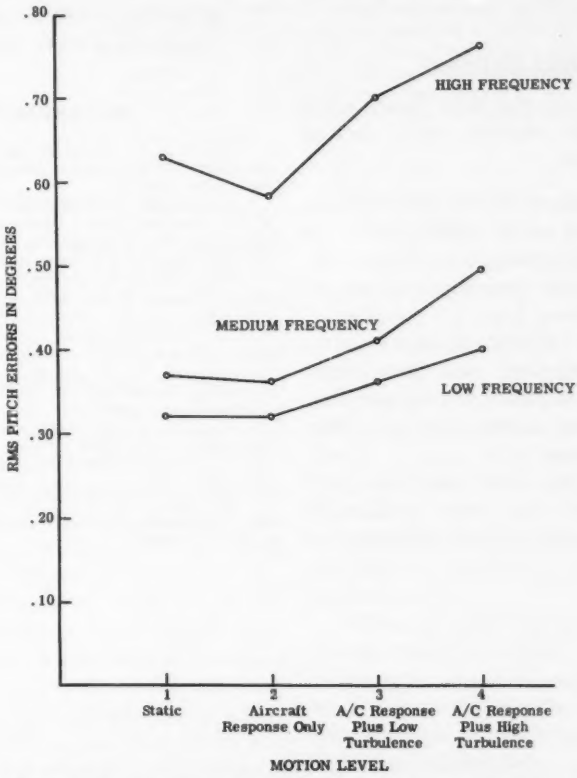

Fig. 5. Effects of motion on tracking errors for each frequency level.

tracking conditions did not differ significantly from a static cockpit. The low-frequency, low-amplitude tracking task was even reported as being monotonous by the pilots. However, the tracking task at the higher levels was realistic and motion effects were more pronounced. It is felt that a more realistic tracking task, in terms of difficulty, is needed in order to assess the full value of motion in a crew station research simulation program.

The effects of vertical accelerations on tracking performance should be of interest to scientists conducting research leading to exact mathematical descriptions of pilot tracking behavior. Error differences of the magnitude found in this study would certainly influence transfer function research of the type conducted by McRuer and Krendel[5] and Ornstein.[6]

In addition this type of simulation should be valuable for assessment of the effects of various

vibration spectra on the physiological processes of flight crews as well as the definition of vibration and acceleration histories for preliminary aerodynamic configurations. Establishment of physiological tolerance bands such as the survey work of Linder[4] would be aided by data from this type of simulation program.

CONCLUSIONS

It was concluded for these experimental conditions on the relatively simple tracking tasks involved that:

1. Simulator cockpit motion of aircraft control response was a valuable cue to the pilots, enabling them to significantly improve tracking performance over the static condition.
2. Any amount of irrelevant motion in the form of turbulence and gust inputs significantly degraded performance over the static and aircraft response motion only conditions.
3. In view of the above conclusions, it is recommended that linear accelerations should be utilized in development of aircraft display and control systems, especially on air vehicles with a high maneuvering requirement or a flexible fuselage.
4. This type of simulation would be useful in defining vibration spectra of particular aerodynamic configurations and to assess physiological effects on the crews while encountering these vibration spectra.

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Factorial Structure of Impact and Damage Variables in Lightplane Accidents[1]

LEE W. GREGG[2] and RICHARD G. PEARSON[3]

A conceptual framework, through which accident variables are defined and certain cause-and-effect relationships are established, is confirmed through application of the technique of factor analysis to a set of lightplane accident data. Relationships between aircraft structural damage and injury to the occupant were seen to increase as a function of proximity. Individual measures of the consequences of impact were found to intercorrelate higher than the implied cause-effect relations from impact to damage.

INTRODUCTION

The purpose of this report is to present a rational analysis of the relationships among a number of variables associated with lightplane accidents together with an empirical evaluation of the adequacy of the logical structure for describing such accidents. The variables are derived from accident reports completed by field investigators and physicians. The kinds of information reported vary widely in reliability from accident to accident and even within a single accident. Some of the raw data consist of ratings of post-crash damage to the aircraft itself; some are inferences based on partial knowledge of particular aspects of the accident; still others are highly deductive judgments in which a variety of sources including statements of witnesses or survivor reports play a role.

Human factors investigations of the findings based on such information have as their ultimate goal effecting changes in the design of aircraft to improve crashworthiness and reduce severity of injury. Questions basic to a number of disciplines arise in the course of these investigations. Apart from the obvious ones of interest to the aeronautical or mechanical engineer and to the applied mathematician, there are fundamental problems of concern to the biophysicist and even to the psychologist. The latter is in a position to make a contribution to crash injury research in several ways.

Although the crash event is one that leads primarily to physical rather than psychological consequences, the data-gathering phase of the research, involving as it does, ratings of damage and interpretations of facts, subject to imperfect recall, presents some purely psychological phenomena related to perception, scaling, and cognition. Furthermore, the psychologist's experience in dealing with multivariate analyses is particularly applicable from a methodological point of view.

Studies of factors influencing perception of damage and their relation to the development of rating scales are in progress. The present study is methodological in approach, applying the technique of factor analysis to a set of lightplane accident data.

RATIONALE UNDERLYING CRASH INJURY INVESTIGATIONS

The logical framework through which the accident variables are defined and certain cause-and-effect relationships are established is presented in Table I. The principles guiding crash injury investigations were developed over a period of years and are described in detail in a manual published in connection with AvCIR's Crash Injury Investigators' School.[1]

[1] Support for this study came from the National Institutes of Health and the Transportation Research Command, U.S. Army.

[2] Carnegie Institute of Technology, Pittsburgh, Pennsylvania.

[3] Aviation Crash Injury Research, Division of Flight Safety Foundation, Inc., Phoenix, Arizona.

Injury to the occupant is considered to be one of four consequences of the impact conditions generated by the crash. Damage to aircraft structures in categories increasing in proximity to the occupant determine the three remaining consequences.

In theory, complete knowledge of the variables created at impact coupled with an engineering specification of the mechanical structures, including the human occupant through which the impact forces are transmitted, would enable perfect prediction of all damage effects. However, serious gaps in knowledge of the primary impact variables exist—even in experimental crash testing where high speed photography provides a means of determining kinematics and where controlled recording of the impact force vectors is possible. That the level of structural detail and the complexity of the expressions needed for computing the transmission of forces would be extremely great is obvious. There is the further question of the extent to which such a molecular description of the accident would provide a manageable body of data.

By identifying somewhat more molar impact variables that account for a major share of the variance in the similarly more molar damage variables, a workable level of explanation may be attained. It is apparent that generality is a desirable attribute for the hypothetical design criteria that crash injury research hopes to provide. Statistical treatment leading to the estimation of population values for gross impact variables and to impact and damage relationships, especially when carried out parametrically by make, model, or type of aircraft, should yield information pointing to specific recommendations of suitable generality.

The AvCIR report form was predicated on the classes of information contained in Table I. The essential hypothesis under consideration

TABLE I

Accident Factors and Variables

	Factor	*Variables*
Cause	Impact Condition	Estimates of impact velocity and angle
		Judgments concerning nature of the terrain and attitude of aircraft at impact
		Measures of gouge depth, length and stopping distance
		Crash sequence including objects struck in primary and secondary impacts
Effects	Damage, Injury to the Occupant	Degree of injury for specific regions of the body
		Composite injury severity rating
	Damage, Occupant's Structural Environment and Closely Associated Objects	Ratings of damage to structures adjacent to occupant including seat condition, instrument panel
	Damage, Occupiable Structures Cabin or Cockpit	Ratings of damage to various parts of occupiable area
	Damage, Non-occupiable Structures	Ratings of damage to nose, wings, tail and major structures

is that field investigators are able to make the kinds of discriminations and judgments required to complete such forms. It should then be possible to derive from their reports the values for variables defined in the Table and reproduce essentially the same factorial structure from the relationships among the variables. In other words, Table I is a closed conceptual system that purports to be an adequate statement of certain causal or correlational relationships descriptive of the accident events. If data obtained in the field and collected with this logical framework as a guide yield the same factorial structure, then we would consider the conceptual framework to be a satisfactory tool for accident analysis. The question of degree of utility will not be considered since there are no alternative structures available for comparison.

From a psychological viewpoint, it should not be surprising to find that the factorial structure is substantiated by data obtained in the context of that structure. Instructions to the field investigators, the layout of the report form and a number of other aspects of the data collection system tend to emphasize the separateness of the categories for the several variables. At the other extreme, it would not be entirely unreasonable to suggest that only a single general factor might emerge with each variable uniformly related to every other variable. Such could be the case if the investigators were unable to detect differential degrees of damage or simply responded to the overall severity of the accident in such a way that any true differential effects were obscured by random or error factors. The latter possibility is remote. It is expected that the factor analysis of the accident variables will not exhibit a pattern of factors. Any differences between the obtained pattern and that of Table I would suggest that modification of the conceptual framework is in order.

A more precise statement of the findings that are expected from the statistical treatment of the empirical data is contained in the hypotheses that follow.

(H:1) A factor analysis of the intercorrelation matrix of the accident variables should produce a set of at least five factors for which the defining factor loadings will be associated with the variables as classified in Table I.

(H:2) Since the categories defining the damage to the aircraft structure are in order of proximity to the occupant, the correlations between them and degree of injury (damage to the occupant himself) should increase as a function of proximity.

(H:3) Since the damage variables (all categories) are simply different aspects of the consequences of an accident and hence may be considered different ways of measuring

TABLE II

List of Accident Variables

Name of Variable	*No. of Scale Values*	*Mean*	*S.D.*
1. Pitch	8	0.2404	1.0754
2. Roll	8	2.3376	1.8206
3. Terrain at impact	4	1.7077	0.7379
4. Impact velocity	80	5.7012	2.4945
5. Impact angle	7	3.8051	1.6518
6. Stopping distance	19	14.6298	2.4862
7. Gouge depth	21	12.5844	1.5446
8. Nose damage	10	2.3311	1.4641
9. Left wing damage	8	1.7662	1.4540
10. Right wing damage	8	1.6168	1.2017
11. Tail damage	8	1.4025	1.1079
12. Empennage damage	8	0.5454	0.7820
13. Cockpit top	5	1.1428	1.0347
14. Cockpit front	5	1.4545	0.9609
15. Cockpit bottom	5	1.1753	0.8069
16. Cockpit left	5	1.1233	0.8629
17. Cockpit right	5	1.0779	0.8719
18. Cockpit, amount of damage	5	1.3571	0.8950
19. Seat condition	9	1.2402	1.9241
20. Occupant environment damage	5	2.3571	0.9979
21. Instrument panel damage	8	1.5974	1.5141
22. Injury severity	8	3.9220	2.3118
23. Head injury	8	3.3831	2.6042

the same fundamental dimension, the intercorrelations of these variables should be higher than the correlations between impact variables and damage variables. The latter relationships are the implied causal relationships. But the causes of damage are multidimensional. Therefore, no single impact variable should stand in as strong relation to a damage variable as one damage variable bears to another.

METHOD

During the period from 1952 to 1960 AvCIR report forms were used that yielded values for each of the variables listed in Table II. These variables are listed in order with the variables 1–7 for the category, Impact Variables; 8–12 for the category, Damage to Major Structures; 13–18 for the category, Damage to Occupiable Structures; 19–21 for the category, Damage to Occupant's Structural Environment; and 22–23 for the category, Damage (Injury) to Occupant.

A total of 500 accidents was available for analysis. It was decided however to restrict the analysis to accidents where the aircraft's principal impact was with the ground and without prior obstacle collision. Accidents in which the aircraft crashed inverted, came to rest in water, or burned were also excluded. In developing the relationships presented in the next section those measures involving occupant environment damage and injury severity were taken for the group of pilots only. A case was not used if the pilot was thrown from the aircraft as a result of the crash. This screening left us with a sample size of 154 for the factor analysis.

The procedure for the analysis was as follows: (1) obtain the intercorrelation matrix for the twenty-three variables of Table II using Pearson Product Moment r's; (2) perform the factor analysis of these by the Thurstone centroid method of extraction; (3) carry out a factor rotation using the Varimax criteria.[3] All of

TABLE III

Intercorrelation Matri

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000	0.124	−0.010	0.065	0.246	−0.137	0.095	0.152	0.098	0.217	0.115	0.215
2		1.000	0.020	−0.004	0.091	0.032	0.103	−0.022	0.179	0.258	0.010	0.485
3			1.000	0.054	0.039	0.098	−0.192	0.047	0.021	−0.046	0.001	0.029
4				1.000	−0.222	0.519	−0.017	0.166	0.310	0.105	0.152	0.150
5					1.000	−0.427	0.108	−0.008	−0.060	0.025	0.017	−0.219
6						1.000	−0.191	0.039	0.186	0.005	0.094	0.144
7							1.000	0.118	0.058	0.149	0.189	−0.054
8								1.000	0.164	0.190	0.338	0.273
9									1.000	0.387	0.187	0.226
10										1.000	0.390	0.209
11											1.000	0.339
12												1.000
13												
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these operations were done with an IBM 650 computer.

RESULTS

The complete intercorrelation matrix is given in Table III. The final result of the factor rotation is presented in Table IV. A total of nine factors was extracted. It is a characteristic of the computer program that factors are extracted in an order determined by the proportion of total variance that the factor accounts for. The nine factors account for practically all of the non-error variance of the intercorrelation matrix. Hence, a measure of the relative effectiveness of each factor is obtained by dividing the sum of the squared factor loadings on each factor by the sum of the communalities, h^2. When this is done, it is apparent that the last few factors of Table IV explain but little of the total variance.

An attempt to name the factors follows. Although the Varimax criteria are such that general factors are minimized, the first factor of Table IV appears to have substantial loadings on it for nine of the twenty-three accident variables. Nevertheless, Factor I is treated here as a specific factor, Damage to the Occupiable Area, as shown in Table V.

The greatest factor loadings are for those variables associated with the occupiable area of the aircraft. However, variable 20 (Occupant Environment Damage) clearly falls into the group of defining variables.

Factor II is defined as Impact Velocity, as shown in Table VI. The combination of these two defining variables, taken together with the fact that the correlation between them is substantial ($r = 0.519$, see Table III), would appear to cast doubt upon a previous conclusion[2] that they measure different aspects of the overall accident picture. Jointly or separately these two primary impact variables, however, are not sufficient determiners of the crash forces imposed. Still, in so far as the

III

Matrix

13	14	15	16	17	18	19	20	21	22	23	*Variable*
0.203	0.234	0.712	0.206	0.236	0.032	0.032	0.180	0.159	0.209	0.255	1
0.309	0.146	0.070	0.197	0.208	0.109	0.157	0.241	0.129	0.094	0.121	2
0.114	0.187	0.010	0.138	0.106	0.048	−0.051	0.203	0.127	0.112	0.072	3
0.162	0.105	0.158	0.865	0.097	0.036	0.203	0.121	−0.039	0.139	0.171	4
0.248	0.269	0.104	0.140	0.177	0.029	0.106	0.271	0.197	0.317	0.285	5
−0.040	0.248	0.032	−0.453	−0.736	0.004	−0.061	−0.135	−0.250	−0.154	−0.132	6
0.216	0.127	0.142	0.282	0.333	0.093	0.261	0.235	0.142	0.324	0.283	7
0.106	0.405	0.127	0.204	0.214	0.019	0.085	0.243	0.233	0.276	0.280	8
0.346	0.118	0.179	0.256	0.204	0.054	0.178	0.250	0.246	0.250	0.168	9
0.493	0.286	0.217	0.352	0.444	0.188	0.158	0.396	0.151	0.281	0.256	10
0.290	0.389	0.219	0.328	0.331	0.130	0.180	0.357	0.244	0.377	0.298	11
0.169	0.137	0.059	0.064	0.090	0.464	−0.018	0.010	−0.017	−0.048	−0.071	12
1.000	0.483	0.390	0.700	0.686	0.338	0.397	0.774	0.426	0.396	0.341	13
	1.000	0.349	0.543	0.570	0.181	0.348	0.731	0.519	0.483	0.483	14
		1.000	0.529	0.507	0.327	0.324	0.559	0.286	0.439	0.425	15
			1.000	0.790	0.372	0.397	0.741	0.436	0.480	0.464	16
				1.000	0.447	0.411	0.729	0.447	0.486	0.504	17
					1.000	0.267	0.264	0.173	0.133	0.092	18
						1.000	0.432	0.350	0.336	0.287	19
							1.000	0.564	0.516	0.496	20
								1.000	0.349	0.327	21
									1.000	0.870	22
										1.000	23

TABLE IV

Varimax Rotation Factor Loadings

	Factors									
Variable	I	II	III	IV	V	VI	VII	VIII	IX	h^2
1	0.073	−0.135	0.123	0.221	−0.040	0.143	−0.033	0.452	−0.052	0.317
2	0.148	0.009	−0.802	−0.053	−0.049	0.302	0.097	0.236	0.062	0.188
3	0.050	−0.064	0.049	0.027	0.504	0.004	0.029	−0.031	0.023	0.267
4	0.034	0.694	0.121	0.121	−0.037	0.098	0.150	−0.060	0.070	0.554
5	0.046	−0.383	0.257	−0.156	0.067	0.023	0.174	0.384	0.135	0.440
6	0.017	0.778	−0.113	0.043	−0.022	0.060	−0.202	−0.073	−0.088	0.678
7	0.195	−0.144	0.256	0.065	−0.367	0.103	0.083	−0.046	0.282	0.362
8	0.039	0.057	0.214	0.572	0.027	−0.028	0.133	0.055	0.001	0.400
9	0.077	0.241	0.133	0.135	−0.001	0.535	0.154	0.033	−0.156	0.435
10	0.264	−0.199	0.109	0.290	−0.014	0.606	−0.091	0.043	0.115	0.557
11	0.192	0.060	0.209	0.560	−0.037	0.190	0.066	−0.103	0.054	0.453
12	0.006	0.158	−0.199	0.569	0.028	0.160	−0.074	0.135	−0.034	0.440
13	0.578	0.029	0.090	0.071	0.116	0.527	0.249	0.233	0.279	0.834
14	0.379	−0.123	0.267	0.444	0.269	0.022	0.428	0.184	0.208	0.760
15	0.551	0.127	0.313	0.001	0.061	0.082	0.157	−0.024	−0.060	0.457
16	0.750	−0.007	0.266	0.164	0.135	0.188	0.110	0.115	0.142	0.759
17	0.786	−0.068	0.277	0.201	0.030	0.189	0.065	0.141	0.179	0.832
18	0.574	−0.008	−0.056	0.011	−0.122	0.057	0.045	−0.012	−0.110	0.366
19	0.383	0.061	0.170	0.013	−0.207	0.109	0.442	−0.005	0.080	0.436
20	0.590	−0.010	0.246	0.188	0.323	0.259	0.425	0.166	0.266	0.895
21	0.322	−0.216	0.180	0.178	0.160	0.164	0.483	0.038	−0.090	0.510
22	0.239	−0.041	0.874	0.156	0.025	0.163	0.167	0.071	0.012	0.908
23	0.241	−0.001	0.867	0.131	0.021	0.069	0.093	0.175	0.071	0.876

TABLE V

Factor I, Damage to the Occupiable Area

Variable	*Loading*
13. Cockpit top	0.578
15. Cockpit bottom	0.551
16. Cockpit left	0.750
17. Cockpit right	0.786
18. Cockpit, amount of damage	0.574
20. Occupant environment damage	0.590

TABLE VI

Factor II, Impact Velocity

Variable	*Loading*
4. Impact velocity	0.694
6. Stopping distance	0.778

need exists for a better understanding of the circumstances surrounding a crash event, those concerned with accident investigation should strive for greater reliability and validity in their estimates of impact velocity and stopping distance.

Factor III is clearly Injury Severity, as shown in Table VII. The correlation between these two defining measures is 0.870 (see Table III). They were the only injury variables included in the factor analysis and it is not surprising

TABLE VII

Factor III, Injury Severity

Variable	*Loading*
22. Injury severity	0.874
23. Head injury	0.867

that they form a strong group. Those scientists concerned with questions of occupant protection in lightplane crashes should take note of the fact that approximately 76 per cent of the variation in injury severity can be accounted for by severity of head injury.

Factor IV is defined as Damage to Non-Occupiable Area, as shown in Table VIII. The presence of variable 14, Cockpit Front, in this list of major structures indicates that a basic confusion may exist in determining the

ratings for that structure. Of course the absence of variables 9 and 10 (Left and Right Wing Damage) from the list of major aircraft structures poses a problem of interpretation. It could be that this factor is confined to non-occupiable fuselage structures with damage being directed along the longitudinal axis of the aircraft.

TABLE VIII

Factor IV, Damage to Non-occupiable Area

Variable	*Loading*
8. Nose damage	0.572
11. Tail damage	0.560
12. Empennage damage	0.569
14. Cockpit front	0.444

Factor V is clearly Terrain at Impact, as shown in Table IX. The nature of the surface on which the aircraft impacts, its density or hardness, plays a critical role in determining the extent of damage.

TABLE IX

Factor V, Terrain at Impact

Variable	*Loading*
3. Terrain at impact	0.504
7. Gouge depth	−0.367

Factor VI is composed of an interesting grouping of variables, as shown in Table X.

TABLE X

Factor VI, Attitude at Impact: Roll

Variable	*Loading*
2. Roll	0.302
9. Left wing damage	0.535
10. Right wing damage	0.606
13. Cockpit top	0.527

A unique pattern of damage variables representing two categories of structural damage (major structures and occupiable area) have high factor loadings on the only factor in which variable 2 (Roll) has any substantial loading. For the present we will call this factor Attitude at Impact: Roll, but it could turn out to be a counterpart to Factor IV, with attention being directed to damage along the lateral axis of the aircraft. In any event, the pattern makes it clear that an adequate description of an accident must take into consideration the extent to which the aircraft is rotated about its longitudinal axis at impact.

Although the defining variables of Factor VII fit the category previously called "Damage, Occupant's Structural Environment" in Table I, it would seem reasonable in the light of the high factor loading of variable 20 (Occupant Environment Damage) on Factor I to consider an alternative interpretation of the meaning of this cluster. Seat condition and instrument panel damage may tell us something about the consequences of the impact on the occupant himself—specifically whether the occupant remained attached to his tie-down chain or not. Thus we have defined this factor as Occupant Tie-Down Effectiveness, as shown in Table XI.

TABLE XI

Factor VII, Occupant Tie-Down Effectiveness

Variable	*Loading*
14. Cockpit front	0.428
19. Seat condition	0.442
20. Occupant environment damage	0.425
21. Instrument panel damage	0.483

Rather than reiterating the fact that damage has occurred within the occupiable area, a more adequate description of the accident event would be one that tells us the disposition of the occupant—his extent of movement within the occupiable area.

TABLE XII

Factor VIII, Attitude at Impact: Pitch

Variable	*Loading*
1. Pitch	0.452
5. Impact angle	0.384

Factor VIII is defined as Attitude at Impact: Pitch, as shown in Table XII. These variables define a factor related to conditions defining the attitude of the aircraft at impact.

Lack of any substantial loadings for Factor IX preclude its interpretation.

DISCUSSION

Four factors related to the description of the conditions at impact were found. These were Factor II, Impact Velocity; Factor V, Terrain at Impact; Factor VI, Roll; and Factor VIII, Pitch. Further research should be directed toward establishing their generality as descriptive terms and then developing techniques of obtaining reliable, easily applied ways of deriving them from the field reports of accident investigators. A particular type of accident provided the data for this study. However, definition and description of other accident types may well be developed from these primary impact variables. This does not imply that new factors may not emerge, as for example in the case of cartwheeling where different patterns of major structure damage may produce a specific factor for that type of accident.

With respect to the consequences of the impact conditions, Factors I, III, IV and VII appear in part to match the four categories of damage outlined in Table I. The problem of naming Factor VII (Occupant Tie-Down Effectiveness) has already been mentioned. It is conceivable that in lightplane crashes such a factor is minimized because of the relatively limited area of the cabin or cockpit as compared to the larger transport aircraft.

In general, the factor analysis lends partial support to the hypothesis (H:1), that the factorial structure of the accident variables presented in Table I provides a useful framework for reporting and describing lightplane accidents.

What of the remaining hypotheses? For the hypothesis (H:2), variables 8, 14 and 20 may be taken as representing the damage ratings to structures that are increasingly nearer the occupant. Do these exhibit increasing correlations with the injury measures for the occupant? The correlations from Table III are shown in Table XIII.

For both injury measures, only the differences between the pairs of correlations for variables 8 and 14 and for variables 8 and 20 are significant at the 0.05 level of confidence. Note that the correlations for nose damage are less than those for the cockpit front, and that these latter correlations are in turn less than those for the occupant environment. It is apparent then that the relationships between aircraft structural damage and injury to the occupant increase as a function of proximity, and thus the results tentatively support hypothesis (H:2).

TABLE XIII

Correlation of Structural Damage and Occupant Injury

	22. *Injury Severity*	23. *Head Injury*
8. Nose Damage	0.276	0.280
14. Cockpit front	0.483	0.483
20. Occupant environment	0.516	0.496

The deduction on which (H:3) was based also fares quite well. Using variables 4, 5 and 6 (the primary impact variables) the twelve correlation coefficients with the four variables 8, 14, 20 and 22 (the damage variables) were obtained from Table III. The mean of these is 0.164; the highest value is 0.317. The six correlation coefficients obtained by pairing every damage variable with every other such variable have a mean of 0.442; the lowest value is 0.243. Although no precise statistical test of the differences is possible, it appears as if these results support the view that individual measures of the consequences of impact will intercorrelate higher than the implied cause–effect relations from impact to damage.

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The Measurement of Man–Machine Systems Under Field Operational Conditions[1]

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The requirements for and special problems involved in human factors field testing are described. With one exception field testing is simply an extension of laboratory testing to the operational-use environment. The exception is the inability to control and test individual variables. The purpose of field testing is to verify that the system performs according to specification. This can be accomplished by comparing field performance with the system description or "template".

INTRODUCTION

Field testing is as old as the first man who built a wheel and then tried trundling a cart down the path to see if it worked. Commonly it has meant the testing of an equipment under operational-use conditions. Human factors field testing is, however, something relatively new. Up to the recent past (roughly the end of World War II and after) field testing of equipment, even where it was systematically carried on, did not include much consideration of the human component or man–machine relationship. The emergence of human engineering as a distinct speciality has coincided with—or perhaps resulted in—a new interest in the testing of human factors in the field environment.

Human factors field testing can be defined as testing the operability and maintainability of an equipment system to be used by personnel by exercising the entire system, men as well as machines, in systematic programs of operation in the operational-use environment. The special characteristic of these exercises is that systematic attention is paid specifically to testing the man–machine interaction. Because the field tryout of equipment, whether it be a weapon system or a can-opener, appears commonplace and obvious, there may be some who consider human factors field testing as merely a fortuitous byproduct of equipment testing. This paper was written to point out the special requirements and problems involved in satisfactory field testing.

Since field testing requires testing of the system's human factors aspects, the criteria discussed below apply across the board to both the equipment and man–machine aspects.

FIELD TEST CRITERIA

(1) Field testing first of all requires the programming of operations, the equipment operations which must be observed, the operations of personnel who utilize the equipment, and the operations implicit in our field observations. The term "observations" as used here includes all the operations involved in gathering data concerning the personnel subsystem. What this programming consists of will be described in paragraphs (2), (3) and (4) below.

The system to be tested cannot be operated in a random fashion; if it is, the results are almost always invalid. Ground rules for equipment operations must be specified and described formally in system criteria reports, technical manuals, checklists etc. As will be pointed out later in more detail, a complete system description must be available before proceeding with a field test. This system description should, wherever possible, be based on a functional analysis of system operations.

(2) The operations or tasks to be performed by the system under test (both

[1] This paper is based on presentations made at the ONR Ninth Annual Human Engineering Conference, St. Louis, Missouri, June 1–2, 1961, and at the Western Psychological Association meetings, Seattle, Washington, June 15–16, 1961.

equipment and personnel) must be essentially those that the system would perform when used by the ultimate user or consumer. Presumably these have been specified by the system description mentioned above. Exercising the system in non-standard operations would mean that one would have no basis for generalizing beyond the immediate field test.

(3) The conditions of operation must be those that the system would undergo in operational use. For example, if the system is to be operated in a desert, it should be tested in a desert-like environment. If the system must operate under certain conditions with a two-man crew, under others with a three-man crew, then both conditions must be tested. Again, if operational conditions are distorted, one loses the ability to generalize.

(4) Most importantly, all the functions of the system must be exercised, even if one is planning to test only a single hardware subsystem. The functions referred to are those that involve personnel, communications, logistics, procedures, maintenance, command decisions etc. Even if the field tester is concerned only with exercising the ground hydraulic system, he must still exercise all the personnel functions related to ground hydraulics or risk invalidating his test. The requirement of exercising system functions applies, however, only when one tests a system or subsystem; it does not carry down to the component test level.

(5) The measurements that one takes in the field test must be preplanned and systematically conducted. A test plan, at least as detailed as a laboratory experimental design, must be created.[2] The level of detail in this plan must extend to all system aspects affecting the man–machine interaction. The characteristics of the observations to be made must be specified. Once created, the test must be conducted according to the plan. This point is so obvious that further comment seems superfluous; yet many field tests are conducted on a "catch-as-catch-can" basis.

(6) Finally, there must be no manipulation of these operational conditions. Once the operation is set in motion it must proceed without interference to its conclusion. This is an ineluctable condition of a satisfactory field test.

Failing to observe these criteria, the tester may be observing something going on in what he calls a field installation, but this something will not be a systematic field test.

Gradations of Field Testing

There are of course many gradations of the field environment and operational conditions. If we assume that running a field test is an exact and unvarying compliance with all operational conditions, then we shall never achieve the "true" field test. If for no other reason, the very fact of measurement—having someone around to observe operations—implies some deviation from ultimate operational conditions.

True operational use of a system implies that all equipment subsystems ordinarily functioning operationally will be tested simultaneously. Suppose, however, that one runs a test of the propulsion subsystem only, as in a static tie-down test of a missile engine. Providing that all other criteria were followed, should one not call this a field test?

Again, the personnel one uses in a field test may not be exactly what one would have in the truly operational use of the system. They may, for example, be more qualified, more sophisticated, than personnel coming out of "pipeline" schools. One would hardly invalidate the test for this reason.

One reason why one can never perform a completely "realistic" field test, is that for maximum usefulness the field test must be performed at some time prior to the point at which the system is released for ultimate operational use. This applies also even under the principle of "concurrency" in which

R and D and operational systems are developed simultaneously. Since the test will be performed in the R and D phase, the system may change somewhat during or as a result of the test, so that it will not accord completely with its ultimate operational use.

Similarities between Field and Laboratory Testing

It is important to note that with one exception field testing is essentially like any other kind of testing, such as that performed in the laboratory. Let us look at what laboratory testing implies and see whether field testing fits the same bill:

(a) Certain behaviors with specified stimulus inputs and response outputs are selected for examination in the laboratory on the basis of variables of interest to the experimenter. Exactly the same thing applies to field testing: the operations selected for observation are those that are specified for the system; certain aspects of personnel behavior determined by the nature of the field test are selected for measurement.

(b) In both cases the conditions under which the behavior will operate are specified. In the laboratory, if the experimenter wants to study dark adaptation, he places the subject in a darkened room and then observes how quickly a stimulus is discriminated. In the field test, if the tester wishes to study the processes of decision-making in troubleshooting, he either sets up a malfunction situation or—more usually—waits for a malfunction to occur and then places the subject in it with instructions to resolve the malfunction.

(c) In the laboratory hypotheses are developed to describe how the variables under examination should operate; these hypotheses direct the data collection process. In the field test the hypotheses developed deal with whether the various system functions, as designed and developed, will operate as planned. Indeed, the entire field test is the test of the hypothesis that the operating system performs according to the system description.

(d) As for instrumentation, data collection and analysis, these apply in essentially the same way to both the laboratory and the field test.

The field test is then actually only an extension of the laboratory test. The one exception is the inability of the tester to manipulate variables as in the classic independent–dependent variable paradigm. This nonmanipulability of variables stems from the fact that the field test is an "exercise", a "demonstration", a single-hypothesis experiment. That is to say, it is designed to answer only one major question: will the system work? The consideration of individual variables has no part to play in answering this question.

WHY FIELD TESTING?

A field test may be thought of, as did Shapero and Erikson[4], as a verification or validation of the system. What this means is that the system as it performs under actual operational conditions is compared to the specification against which the system was originally designed and built. The term "specification" is used here in the broad sense to include not only contractual requirements, but various types of system descriptions, such as functional analyses, criteria etc.

For example, if the designer specifies that an operation be performed in twelve minutes, will it actually take 12 min; and if not, how long will it take?

The second reason for field testing is that as a corollary of system verification the designer may wish to improve his system product. As a result of testing it may turn out that his system is deficient in some respect when it is compared with its specification. He will then wish to modify the system so that it accords with the specification. The field test is the primary source of the "quick fix".

The laboratory experimenter may wish to verify data on variables previously isolated and tested in a laboratory situation. He may wish to see how these variables perform in a total system context in a fully operational situation.

Conversely, after having performed a field test, one might wish to go back to the laboratory to test certain variables in the classic experimental manner.

The system designer may suspect that he has missed or failed to specify certain operational conditions that will affect his system when it is ultimately used. He cannot find out what these conditions are in the laboratory because the laboratory cannot duplicate the interaction of operational conditions. Therefore he sets the system into operation in the field, and waits to see what unknowns will affect it.

The question may be asked why these purposes cannot be fulfilled in laboratory work. Sheer necessity may compel a field test. Some systems and equipments are so large and complex that one cannot physically or costwise bring them into a laboratory environment without prohibitive efforts.

As a result it is extremely difficult, if not impossible, to display all the necessary operational conditions in the laboratory. If the system designer wishes to see how the total system operates, with all its interactions available, he must go to the field. Because of laboratory constraints, only minimal interactions are possible in the laboratory. It is through these interactions that one may discover new operating effects that one had not anticipated. The one distinguishing characteristic of the field test as opposed to the laboratory test is that the former permits the total system, with all its functions, to operate, whereas the laboratory must deal with only partial systems.

For this reason, field testing provides a quality of realism which is almost impossible to simulate in a laboratory. One of the reasons for this realism in a field test is that the system is allowed to operate unchecked, unhampered by other than its own internal constraints. For example, if the system breaks down in the field, the breakdown is considered part of the system conditions and itself constitutes a stimulus situation in which we can see what the system will do to repair itself. In the laboratory if the system breaks down, we stop the operation, tear up the data and rerun the test. Because of this it is extremely difficult for the laboratory to simulate maintenance operations, particularly trouble-shooting.

PROBLEMS OF CONTROL

One of the features of field testing that bothers experimentalists most is that field testing appears to be fluid and uncontrolled. They complain that all sorts of intrusive variables enter in to confuse the observations. Let us examine this complaint in detail.

When an experimenter says that the field test lacks experimental control, he really means that he cannot achieve the same kind of control over variables in the field test as he could in the laboratory. He is perfectly correct about this. It is important to distinguish between kind and degree (quantity) of control, because while one can (degree) control the field test, the kind of control is not at all comparable to that of the laboratory.

The conditions that have to operate to achieve classic experimental control are:

(a) There are no intrusive factors or events occurring that might confound the test of variables;

(b) The variables to be tested are isolated (act independently of other variables);

(c) Untested variables are controlled by equalizing their effect between groups;

(d) It is possible to compare matched groups or successive conditions or states of the same group.

Intrusive Factors

These intrusive factors are unprogrammed stimulus events. In the laboratory these occur rarely (because the conditions under which a laboratory test is run are severely regulated), and when they do, the test is rejected as invalid.

In actuality, these factors occur just as infrequently in the field situation. What appears to be an unprogrammed stimulus event is often considered so because the system and its operation may not be sufficiently clear to the observer. That is because the conditions under which the system operates in the field environment are much more encompassing than those under which the system operates in the laboratory. For example: A test of a missile launch is programmed, but cannot occur on schedule because it is discovered that the supply of fuel is depleted. Is this an unprogrammed event? Yes, for this particular launch, but not when one considers the system as a whole, because the total system involves conditions under which the supply of fuel is less than required. In other words, the logistic factor—which in the laboratory would be ignored—is a vital part of the missile system test. An "unprogrammed" operation at this time permits one to test the adequacy of the logistic function.

It may be objected that the logistic function deals with purely equipment characteristics. But in reality even if there were no personnel involvements (decision-making, monitoring etc.) in logistics, one could still hardly hope to understand the functioning of the complete system without logistics.

In a field test unprogrammed stimulus events need not occur indiscriminately. As part of the system description there is an implied requirement that the system operate, as far as stimulus events are concerned, according to that description. In other words, having agreed on the ground rules for operating the system, these ground rules must not be changed. If, for any reason, these are violated, then indeed one must write the test off as invalid.

The ground rules under which a system must operate in a field test are:

(a) Only those system variables that are included in the system description are permitted to operate;

(b) When an operation begins it must run its logical course until its objective is accomplished or the system breaks down;

(c) There must be no interference by anyone with the system once it begins to operate;

(d) If the system cannot be tested fully at one time, then a test operation must begin at some system start point and go to its corresponding system end point, as determined by the logic of the system;

(e) There must be no artificial informational or other inputs (unauthorized feedback) to the system by anyone outside the system.

Provided these rules are followed, intrusion of extraneous factors should be no more frequent in field than in laboratory testing.

Independence of Variables under Field Conditions

It was pointed out that it is impossible to isolate variables and to test them under field conditions. There are reasons for this. First of all, testing under field operational conditions implies no interference with these conditions. Pragmatically, the hardware configuration, the system mission and the method of accomplishing the mission, determine the conditions under which system behavior can be studied. One cannot manipulate variables within the system if this manipulation would violate the system's operational rules or the mission requirements.

Moreover, as soon as one artificially isolates these variables, the conditions under which they operate are no longer the ones under which the system would normally operate. The reason for this is the much greater interaction of variables in field testing than in laboratory testing. Field conditions permit these interactions greater degrees of freedom. Hence, the variation of parameters in field testing affects the total system more than it would under laboratory conditions. The result is that when one manipulates variables in a field operating system, one is in effect testing different systems.

There is in any system a range of variation of parameters depending on the number of operating conditions. It is possible to compare these conditions as long as they are implicit in the system. This means that it is possible to compare the performance of a variable along points on a continuum within the same system, but that one cannot compare two variables, one of which is not in the system as described. For example, if a missile system requires a three-man launch crew, one can compare the efficiency of that crew under conditions of normal launch, malfunction, standby etc. One cannot, however, compare the three-man crew with a two-man crew without, in effect, comparing two different systems, one of which requires a three-man crew, the other a two-man crew.

Matching Groups

One can of course compare the same group under varied operating conditions, provided these conditions are a part of the situation under which the system is required to perform. Moreover, one can match personnel as long as they are matched to the same system criteria. This is akin to the interchangeability within the system of identical equipments or components of the same type. However, the system must encompass as part of its functional characteristics the varied operating conditions and the personnel used in such comparison studies.

THE SYSTEM DESCRIPTION

The essential purpose of the field test is not to study the effects of individual variables, but to determine how the system as a whole operates.

From this standpoint it is therefore not really necessary to manipulate individual variables to answer this question. One must, however, have some way of analyzing system performance other than the traditional methods based on isolation of variables (such as analysis of variance, for example).

To the extent that we can develop a methodology that enables us to understand how the system performs, even when we cannot dissect it into elements, we can utilize field operational situations as validly (for our purposes) as we can utilize classical laboratory situations.

This method of control and analysis is based on what we have called a system description (in preference to the term "model", which has connotations of quantification that the system description does not have). The system description is in turn based on an equipment-task-functional analysis.

In an equipment-task-functional analysis the operation of the system is examined to determine the functions performed by the system. The major functions to be performed by personnel (communicating, monitoring, deciding, controlling etc.) in relation to these system functions are also described. Interrelationships among equipments are shown by input–output lines, while interrelationships among personnel are shown by communication arrows. When displayed pictorially the resultant analysis is called a "template",[1] which implies a pattern which can be overlaid on the actual test performance of the system. A sample template is shown in Fig. 1.

Using the template, it is possible to determine if the system behaves like the template and where it does not, what deviations have occurred. The basic assumption we must make is that if the system actually behaves in the manner described by the template, then certain relationships must exist because the template could not operate without them. By plotting a template of the actual system performance and then comparing it with the predictive template, it is possible to see exactly where deviations have occurred.

Templates are unnecessary (although desirable) in laboratory work. Because one deals in the laboratory with only partial aspects of a system, the experimenter can do nicely with isolated hypotheses based on an examination of the literature or his personal "hunch".

The system description differs from the usual laboratory hypothesis in terms of complexity and scale. The description must con-

tain all relevant system interrelationships, functions etc., while the hypothesis need not. The hypothesis in fact is merely one part of a system description. Because of the complexity of even a simple system (when it is observed as a whole) one must have a system description or template in field testing. A template is in fact necessary to determine how the system test should be set up.

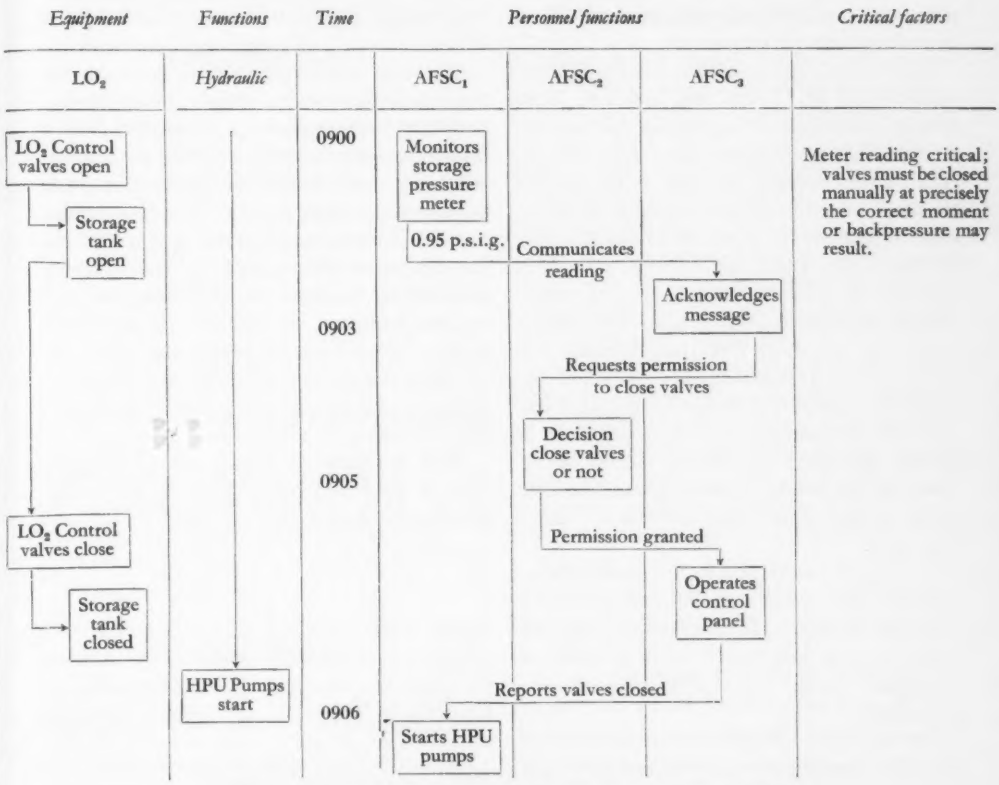

Fig. 1. Abbreviated section of a system description ("template").

FIELD TEST GENERALIZATIONS

What we learn from field testing is not quite as obvious as one might think. There are of course all the purposes of field testing which are satisfied when we field test: system verification, product improvement, discovery of new operational conditions etc. But is there anything we can learn beyond this? This is basically a question of what generalizations we can make from field test data that might be applied to the different systems we deal with and to systems research or psychology in general.

As an example, consider missile development. Since 1946 an entire family of missile systems has grown up, ranging from the improved V-2 to the present Minuteman and Polaris. There were surely generalizations to be made among the personnel aspects of these missile systems. Unfortunately, as Shapero *et al.*[3] pointed out in their survey, there have been almost no systematic human engineering (field) tests conducted. The result is that

information of great potential value has probably been overlooked.

If such generalizations have not been made, it is because field testers have not known how to make the most of their field tests; they have not approached their testing with a systems orientation. They have not been aware of what they could get out of their tests as far as generalizations are concerned.

One can only guess at what these generalizations might be. There are, however, many system interactions, whose nature we can only surmise, that might be revealed. For example, each system operates through time: what is the frequency of error as a function of operating time, as one moves closer to completion of a function? How does one combine subsystem measures to secure a measure of total system output? How do communications link system operations and how does one measure the effect of these communications? What is the relationship between measures of operation and measures of maintenance? Upon reflection it appears that there is a whole microcosm of questions that reside within a system field test, whose answers would apply to systems research in general.

The specific measurement techniques developed for field testing weapon or space systems might also be applied to other areas where field observation is commonly utilized, such as industrial, social, child and even clinical psychology.

Human factors field test data can tell us much about how personnel perform in real-life group work situations. It is difficult at best to go into established industrial environments to study systems about whose origins and development we know little. Military and space systems provide work situations to whose development we as human engineers have contributed, which we can observe as they do develop, and where, most important, testing is a fundamental part of their development.

The small size of our data samples in each field test has been raised as an objection to the possibility of gathering any generalizable data. Because of our small sample size we shall have to utilize successive field tests on different systems in order to accumulate the necessary N. For this very reason each of these field tests must be performed in a systematic fashion if we are to be able to combine test results.

We must not forget that the field test environment provides us with an admirable test bed in which to gather much needed data on a wide range of human factors problems. When we build systems for the government, the government usually provides us with a facility for testing the adequacy of that system. Where we can utilize that test facility for gathering information relevant to psychological and systems problems, we double the utility of the facility. If we have the vision, any single test situation enables us to study operability, maintainability, human reliability, personnel factors, job environment—a whole host of things.

What is needed to extract this information from a field test situation is a systematic orientation toward field testing.

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A 1961 Compilation and Brief History of Human Factors Research in Business and Industry

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INTRODUCTION

Much of the material upon which this paper is based was developed for an invited presentation to the Psychology and Social Science Panel of the United States Air Force Scientific Advisory Board, in January 1961. The panel Chairman had contacted numerous governmental agencies active in human factors and related work and had requested briefings which would cover:

- the nature and extent of human factors activities,
- the size and budget of current and projected programs,
- the number and type of professional and technical people employed in this work,
- examples of studies being conducted,
- examples of areas which need greater attention and support.

The author was requested to present similar material which would be descriptive of business and industrial programs. In order to develop a representative picture of industrial human factors research, more than 130 representatives of industry, consulting firms, and advisory groups were contacted by letter and asked to describe their programs and list their current and projected activities in this field (see Appendices). Previous surveys of a similar nature and related material were used for supplementation.[1–12]

More than 50 per cent of the organizations contacted supplied information. The responses received, many of which were very lengthy, were generally thorough, frank, and professionally introspective.

The briefings presented to the Scientific Advisory Board Panel members and guests provided an excellent opportunity for exchange of information and a means for informing high echelons of the Air Force and Department of Defense of the activities, interests and problems of human factors specialists.

In order to give a wider dissemination of the industrial information presented to this panel, the author was urged to publish the findings of the survey and the human factors studies being conducted by industry.

The compilation of studies is by no means complete. A few of the companies contacted preferred not to publicize their activities, some companies failed to respond to the survey, and some were not contacted. Government and university programs, with but a few exceptions, were not included in this survey.

Judging from the survey responses, the human factors field is rapidly coming of age and its practitioners and supporters are accepting the field for what it is and aspires to be. There is ample evidence of organizational support for human factors research as demonstrated by the rapid growth of the field, the diversity of activities, the extent of funding, and the hierarchal position of the programs within industry.

In the following pages an attempt is made to provide brief answers to questions such as:

How is human factors research defined?

How did the specialty evolve?

What is its growth history?

How are people distributed geographically?

What academic specialities are representative of the field?

What type of literature is produced?

How are the programs staffed and supported?

What type of activities comprise the field?

What are typical salaries?

What trends are observable?

What work needs to be done?

What are some of the operating problems?

What kind of studies are being conducted by representative companies?

HUMAN FACTORS RESEARCH DEFINED

The field has been defined many times by many people and, apparently, no one definition has been able to satisfy everybody. One definition of duties of the Human Factors Specialist, as given in a System Development Corporation National Salary Survey,[12] is presented in part below:

The Human Factors Specialist: "establishes, conducts, coordinates and applies major research studies in the social, behavioral or physiological sciences; contributes to design, development and operation of man–machine, weapons or other complex systems concepts; utilizes psychological principles of human behavior, knowledge of human physical and mental characteristics, abilities and limitations, and principles of human engineering."

Typical Duties: "designs and implements scientific experiments and other research methodology to study human factors areas as they pertain to the operation of man–machine, weapons and other complex systems and concepts. Evaluates existing or proposed man–machine systems and subsystems in terms of human physiological and psychological requirements so that optimum system reliability and durability from a human input standpoint are established. Consults with design engineers and other professionals prior to, during and after design and development of systems to assure optimum operation in terms of human capabilities, limitations, and variables. Provides the most current state-of-the-art information in his particular field of specialization."

HISTORICAL MILESTONES

The evolution of the field, broadly referred to as human factors, is characterized by spotty development during the 1940's and early 1950's, and by steady, if not spectacular, growth in the mid-1950's.

During the early 1940's, individuals and groups were identifying their work as Aviation Psychology, and the term "human factors" was beginning to be associated with equipment design.

Some, but certainly not all, of the early pioneers in the field include: Dr. Lynn Baker, Dr. Leonard Carmichael, Dr. Al Chapanis, Dr. Julian Christensen, Mr. Ren Contini, Dr. Douglas Courtney, Admiral Louis de Florez, Dr. Jack Dunlap, Dr. Paul Fitts, Dr. W. Garner, Dr. Walt Grether, Dr. W. E. Kappauf, Dr. George Kelly, Dr. John Kennedy, Mr. Stan Lippert, Dr. Max Lund, Dr. Ross McFarland, Dr. A. Melton, Dr. C. Morgan, Dr. Harry Older, Dr. Cliff Seitz, Dr. Arnold Small, Dr. Franklin Taylor, and Dr. Alex Williams.

Several government and university programs were started during the mid and late 1940's and early 1950's to provide the foundation upon which the field would be built. Examples of some of these include: the Harvard Systems Research Laboratory; the Navy and Air Force Schools of Aviation Medicine; the New York University Human Engineering Project (Cadillac III); the Johns Hopkins and the Tufts College Applied Psychology Laboratories; the U.S. Air Force Aviation Psychology Laboratory; the Naval Special Devices Center, Naval Electronics Laboratory, the NRL Engineering Psychology Branch, and the Johnsville Acceleration Laboratory; the Air Force Personnel and Training Research Center; RAND; System Development Corporation; Human Resources

Research Office; Army Medical Research Laboratory; Naval Medical Research Laboratory and the USN Aircrew Equipment Laboratory.

During this period several aircraft companies (e.g. Douglas, Chance-Vought, Lockheed) began to utilize human factors research contributions in equipment design, and in the development of seats, flight stations, training programs and safety procedures.

A number of significant documents appeared during these formative years, such as: *Human Factors in Undersea Warfare, Human Factors in Air Transport Design, Tufts Handbook of Human Engineering Data, Applied Experimental Psychology—Human Factors in Engineering Design, Human Engineering Guide for Design Engineers,* and *Visual Presentation of Information.*

In the 1950's a number of educational programs were initiated to provide training for people interested in human factors research (e.g. Ohio State, University of Illinois, Johns Hopkins, U.C L.A., U.S.C., Tufts University, Columbia, Post College of Long Island University, and University of Michigan).

In the years following 1951 the Air Force program of Qualitative Personnel Requirements Analysis was beginning to become an important part of aircraft and equipment development under the direction of the Air Force Personnel and Training Research Center. Documents produced by this organization provided foundation material for the Air Force Personnel Subsystems program and their current Bioastronautics program.

HUMAN FACTORS ORIENTED PROFESSIONAL GROUPS

The Office of Naval Research held its first Annual Human Engineering Conference at Washington, D.C., in October, 1953, with approximately fifty people attending. Nine companies, six governmental agencies and four university and non-profit organizations were represented at the meeting. The Ninth Annual ONR Human Engineering Conference was held in June, 1961, at St. Louis, Missouri with an attendance of 140 people and representation from forty-four companies, twenty-five governmental agencies and twenty-two universities and non-profit organizations. It should be noted that attendance at the ONR meetings is by invitation and, although the broadest organizational coverage is encouraged, the attendance is kept as small as possible.

The first annual meeting of the Flight Safety Foundation was held in 1948 at the U.S. Naval Training Devices Center, Sands Point, Long Island, with thirty-one in attendance representing four countries. Their thirteenth annual meeting in 1960 at Chandler, Arizona, was attended by 161 representatives of twenty-three countries.

In January, 1957, the Engineering Psychology Division 21 of the American Psychological Association was organized with a charter membership of 184. The 1960 membership of Division 21 was 278.

The British Ergonomics Society was organized during this period to represent professional people engaged in work broadly defined as human factors.

After the Annual ONR Human Engineering Conference at Tulsa in September, 1957, the Human Factors Society of America was formally organized with a charter group of ninety-two. This group was formed to serve as an interdisciplinary society for professional and technical people engaged in human factors research, human engineering, biotechnology, biomechanics, aerospace medicine, and other related fields which emphasize man–machine or man–equipment relationships. This society, as of June, 1961, has a multi-specialty membership of 654, representing thirty-four states and six foreign countries,[11] with fifteen corporate sustaining memberships. The growth of this society is presented in the following graph (Fig. 1) developed by Stanley Lippert, Editor-in-Chief of the Human Factors Society. A geographical distribution of members of this society is also presented in Table I.[11]

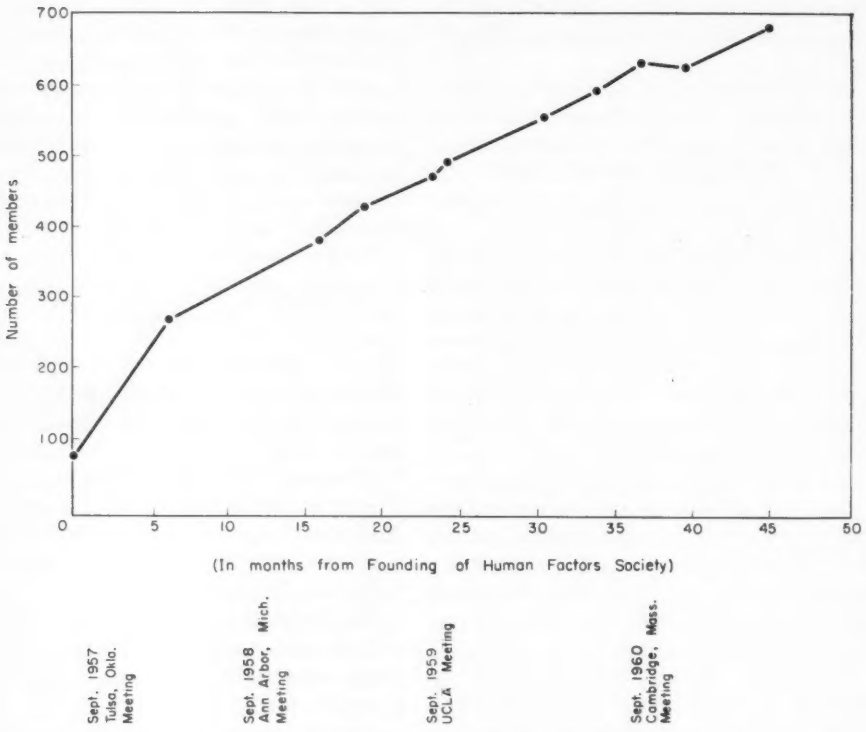


Fig. 1. Growth history—Human Factors Society (based on the Mailing Lists—*Human Factors Journal*, developed by Stanley Lippert).

A significant organization with the earliest interest in human factors problems is the Aeromedical Association (recently redesignated as the Aerospace Medical Association). This group has made substantial contributions to the field through its annual meetings and its publication of the Aerospace Medical Journal. Attendance at the annual Aerospace Medical meetings now numbers in the thousands, and is truly international. Numerous other societies have formed human factors oriented groups within their organization, such as the ASME, IRE, IAS, AIEE, SAE, to mention just a few.

This list of pioneering societies, and the meetings, symposia, and the like devoted to human factors topics, is not intended to be all-inclusive and can certainly be expanded.

TABLE I

Geographical Distribution of Members of the Human Factors Society (Taken from the January, 1961, Human Factors Society, Directory of Members)[11]

Australia	2
Canada	7
Great Britain	1
Netherlands	1
Sweden	1
Turkey	1
APO—New York	4
APO—San Francisco	2

United States of America	
Alabama	2
Arizona	7
California	222
Colorado	10
Connecticut	15
Delaware	1
Dist. of Columbia	11
Florida	10
Georgia	2
Illinois	4
Iowa	2
Kansas	3
Louisiana	1
Maine	2
Maryland	36
Massachusetts	30
Michigan	20
Missouri	1
Montana	1
Nebraska	3
New Jersey	31
New Mexico	2
New York	68
Ohio	29
Oklahoma	4
Oregon	3
Pennsylvania	28
Texas	16
Utah	2
Virginia	17
Washington	9
Wisconsin	7

BUSINESS–INDUSTRY GROWTH

By 1954 a number of the significant producers of aircraft equipment were taking part in various aspects of human factors research. The Lockheed Aircraft Corporation (Georgia Division), for example, organized its human factors effort in the Fall of 1954, but the field already had a strong start with the concurrent developments of the Air Force Personnel and Training Research Center program and the Army–Navy Integrated Instrument Program. (The ANIP program is an inter-service effort to improve flight station design through a multi-discipline and multi-company approach.)

The following graph (Fig. 2) which is based on less than complete data,[3, 4, 6, 10–12] gives some impression of the growth history of industrial human factors research activities. The figures for the years prior to 1956 reflect, primarily, aircraft and related industry programs. Subsequent to 1956, the figures include missile companies and other businesses not solely identified with the aircraft industry.

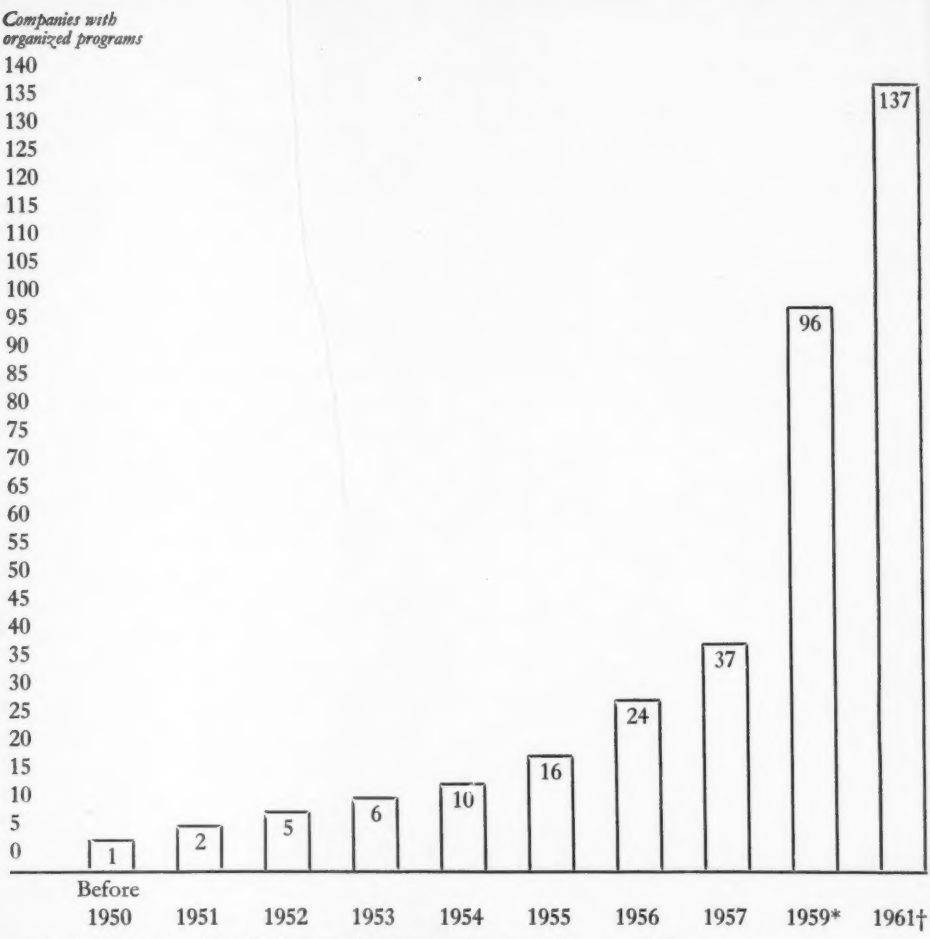
A noticeable growth occurred between 1954 and 1957 coincidental with the Department of Defense emphasis on the weapon system concept in aircraft development. However, the most significant growth has occurred between 1957 and 1961, concurrent with the expansion of missile and man-in-space programs.

In 1956 it was estimated that at least 250 people were employed in industrial human factors and related research work.[3] Toward the end of 1957, an estimated 450 people were employed in this field.[8] Findings from the 1960 System Development Corporation, National Salary Survey of Human Factors Professional Personnel,[12] and the author's 1961 survey[6] indicate that approximately 1300 people are now employed within business and industry in work broadly described as human factors research.

ACADEMIC SPECIALITIES AND DEGREES

The field of human factors is most definitely characterized by its multi-discipline composition. Although the various surveys of the field differ somewhat in the findings in this area, there is general agreement that psychology and engineering specialties are predominant.

The following table of academic specialities and degrees reflect the findings of several surveys as well as the author's most recent one[3, 4, 6, 9, 11, 12] (Table II).



* Includes sixty from SDC 1959 survey plus thirty-six from author's surveys.[6, 12]

† Includes sixty from SDC 1960 survey, sixty-two from author's survey, and fifteen from January, 1961, Human Factors Directory.[6, 11, 12]

Fig. 2. Growth trend—industrial human factors research activity

REPRESENTATIVE SALARIES

The following information, developed by Charles W. Simon[9] of Hughes Research Laboratories, presents the salary ranges of human factors specialists by academic specialty, experience level, degree level, type of organization and geographical area. This information was obtained from 253 members of the Human Factors Society who were contacted in 1959. The sample represents more than 63 per cent of the society membership at the time of the survey (see Table III).

INDUSTRIAL HUMAN FACTORS PROGRAMS

The author's most recent survey[6] of business and industry reveals some interesting aspects of the human factors programs, such as:

The working groups range in size from one to sixty-five people with a mean size of

TABLE II

Academic Specialties of Human Factors Personnel

Specialty	1957[3]	1958[4]	1959[12]	1960[12]
Psychology				
General	61		453	678
Experimental		99		
Industrial		18		
All Other		16		
Engineering				
General	57		67	98
Mechanical		49		
Industrial		1		
Electrical		36		
Aeronautical		7		
All Other		8		
Engineering and Psychology				
Physics	4	14	14	23
Physiology	8	12	8	9
Education			17	28
Mathematics/Statistics	1	12	17	15
Industrial Design	1	6		
Medicine	4	9	3	5
Anthropology	1	6		
Anthropology/Sociology			40	89
Business and Economics			4	38
Biology			8	5
Liberal Arts			13	33
Other Social and Behavioral Sciences		4	8	34
Other Physical and Biological Sciences		2	5	28
Other Than Above	29	53	9	9

ten. Estimates of projected growth for these groups indicate that from 10 to 50 per cent increase is anticipated in the near future. One of the respondents predicted a human factors group of 150 within the next few years.

Although the psychological specialty continues to predominate the field, there is ample evidence that other specialty areas are increasing in number. The functions and responsibilities of most of the programs have been broadened in scope, and participation by human factors people is virtually standard on most government systems developmental projects. Activities range from purely advisory to regulatory functions, but the trend is toward human factors specialists participating as members of study or design teams contributing their specialty knowledge in much the same manner as do the specialists in other disciplines (e.g. structures engineers, aerodynamicists, electronics engineers). The activities within the field have broadened to a point which makes concise description extremely difficult. If a human is part of a system (as he usually is) his requirements, desires, capabilities and limitations are concerns of the human factors specialists.

The majority of human factors work is supported through government contract, yet there is evidence of an increase of company support for fundamental as well as applied human factors research.

The positions occupied within the companies by the various human factors programs are extremely varied and a standard pattern has not yet evolved. The size, responsibility and support of such programs appear to be functions of government contract requirements, acceptance of the program by management, nature of the business, and personalities of the key human factors people.

Acceptance at the working level by other disciplines seems to be increasing and active resistance to human factors activity is lessening as suggested by the increased demand for the services of the human factors specialists. Although the "head shrinker" label is still heard from time to time, it is interesting to note that the engineers and physical scientists working in the human factors field frequently share this label.

TABLE III

Salary Distribution—Human Factors Professional Personnel*

			Yearly salary (in thousands of dollars)							
n=253		*Total* %	< $5 0.5	5–7.5 10	7.5–10 26	10–12.5 23	12.5–15 25	15–20 11	20–25 3	> $25 1.5
Profession										
Psychology	139	55		12	30	34	38	18	4	3
Engineering	57	22.5	1	6	16	12	15	6		1
Physiology	12	5		1	4	3		2	2	
Anthropology	9	3.5		3	2	2	2			
Psychology and Engineering	11	4		1	4	3	1	2		
Education	5	2			2	1	2			
Medical	4	1.5			1	1	1		1	
Other	16	6.5	1	2	8	1	4			
Years' Experience										
0–2	29	12	2	6	12	4	4	1		
2–5	69	27		12	28	19	8	1	1	1
5–10	91	36		7	21	21	30	9	2	1
10+	64	25			6	13	21	17	4	3
Degree										
Doctors	109	43		3	14	25	37	20	6	4
Masters	69	27		13	24	19	12	1		
Bachelors	62	25	1	8	26	12	10	5		
None	9	3.5	1	1	2	1	3	1		
M.D.	4	1.5			1	1	1		1	
Organization										
Academic	26	10	1	7	8	3	6	1		
Institution	14	6		1	6	2	3	1		1
Government	41	16		6	13	12	10			
Industry	128	51	1	7	32	35	34	18	1	
Consulting	36	14		4	7	5	9	3	5	3
Academic and Consulting	4	1.5						3	1	
Other	4	1.5		1	1	1	1			
Area										
East	135	53	2	12	37	27	37	10	6	4
West	118	47		13	30	30	26	18	1	

* Prepared by Charles W. Simon, Hughes Aircraft, for Human Factors Society Bulletins, August–September 1959.

COMMON ELEMENTS OF PROGRAMS

There is no one industrial program known to the author that can be described as being typical, but there are several elements common to the many programs. It was found that many of the groups perform staff type functions. The size of groups in larger companies is generally greater than twenty but less than one hundred. The most frequent specialties represented are psychology, engineering, physics and physiology, in that order. The activities consist, most frequently, of applying human engineering principles to product design, establishing human factors requirements for new systems, and evaluating potential human performance in complex systems. Government agencies and educational institutions are conducting most of the fundamental research and therefore are producing most of the basic information. Industry is primarily interested in the application of this basic research to everyday problems but is beginning to recognize that the government–university source is insufficient to resolve all of the problems with which industry is being confronted. Therefore, some companies are beginning to support more fundamentally oriented human factors research studies. Many of the programs are organizationally located at section, department or division level. (The ascending hierarchy for these labels is: group—section—department—division—branch or directorate.)

Psychologically trained people are in charge of most of the industrial programs. However, a number of the groups are under the direction of human factors oriented engineers or aeromedical specialists. Salaries paid experienced people in this field compare favorably with comparably qualified specialists in other disciplines but vary widely from industry to industry. Most of the groups work in, or closely with, engineering and research units of the companies. Considerable support and a fair amount of recognition have been given by industry to human factors activities. The multi-division companies generally support human factors programs at each of their major divisions on a more or less autonomous basis.

Few programs have been dropped by their companies although the management and direction of the activities have changed significantly in a number of the companies (e.g., in one or two instances the medical aspects of human factors have overshadowed the psychological and engineering aspects. In several instances the hardware design aspect of the field has preempted the research activity).

There are probably many more less apparent common elements of these industrial programs, yet it is much easier to point out the variations than the similarities. Each company program seems to be tailored to the specific needs of that company and to its operating philosophy and image.

HUMAN FACTORS LITERATURE OUTPUT

Stanley Lippert, of Douglas Aircraft, has made a recent analysis[7] of the literature produced by human factors people and the specialty fields producing this literature. He notes that of the fifty articles published in the first two volumes of the Human Factors Society Journal, three governmental agencies, ten universities, and ten industrial concerns constituted the affiliation of 80 per cent of the article producers. Two out of every three articles were prepared by psychologists; physiologists contributed one out of seven; and engineers, one out of ten. This distribution is not surprising in view of the composition of the Human Factors Society. One could consider that psychologists are more prolific than the other specialties, or that there are many more psychologists engaged in human factors work than other disciplines. However, this analysis is too preliminary and the sample is too restrictive to permit sound generalizations to be made.

Lippert reviewed the bibliographies of human factors literature compiled by McCollom and

Chapanis and by Tufts College[1], which comprised more than 15,000 non-duplicate references. He noted that two-thirds of the literature is contained in five topics, three-fourths in six topics, and more than 90 per cent in ten topics.

Lippert noted that the Tufts bibliographies have averaged 3000[2] new entries per year between 1955 and 1958. By 1960 the human factors literature consisted of over 25,000 items.

The topical analysis of the McCollom and Chapanis and the Tufts Bibliographies is presented in Table IV.

TRENDS

Extrapolations from the preceding information and the survey responses suggest a number of trends for the human factors field within the foreseeable future:

The number of business and industrial organizations supporting human factors research will continue to increase.

The number of people employed in this and closely related disciplines will continue to increase, at least for the next several years, at a rate of between 200 and 300 per year.

The literature produced within the field should equal or exceed 3000 titles per year.

Salaries will continue to rise, partially as a result of the limited supply of experienced people, but also because of the increased need for this specialty in space-age systems activity.

TABLE IV

Analysis of McCollom and Chapanis, and Tufts Bibliographies*

Classification of Document per Tufts topical outline	*McCollom and Chapanis*		*Tufts, 1955–56*		*Tufts, 1956–57*		*Tufts, 1957–58*		*Tufts Total (3 years)*		*Tufts av./yr*		*McCollom and Tufts*	
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%
1. *Human engineering, methods equipment, general references*	612	11.16	102	8.80	245	9.28	317	7.26	803		268	8.25	1415	9.29
2. *Systems of men and machines*	266	4.85	102	3.72	181	6.85	323	7.40	606		202	6.22	872	5.73
3. *Visual inputs and processes*	1411	25.72	706	25.77	572	21.66	1230	28.19	2508		836	25.74	3919	25.73
4. *Aud.: Includes speech prod. and intelligibility*	599	10.91	436	15.91	405	15.34	544	12.69	1395		465	14.32	1994	13.09
5. *Other sensory inputs and processes*	108	1.97	55	2.01	41	1.55	73	1.67	169		56	1.72	277	1.82
6. *Input channels: Choice and interaction*	86	1.57	27	0.99	17	0.64	44	1.01	88		29	0.89	174	1.14
7. *Body measurements: Basic physiology, etc.*	279	5.09	205	7.48	209	7.91	434	9.95	848		283	8.71	1127	7.40
8. *Design of controls and integration with displays*	145	2.64	111	4.05	104	3.94	85	1.94	300		100	3.08	445	2.92
9. *Layout of panels and consoles*	18	0.33	21	0.77	13	0.49	17	0.39	51		17	0.52	69	0.45
10. *Design of work space, equipment and furniture*	244	4.45	126	4.60	134	5.07	240	5.50	500		167	5.14	744	4.88
11. *Clothing and personal equipment*	0	0.00	104	3.80	124	4.70	139	3.19	367		122	3.76	367	2.41
12. *Special environmental factors affecting performance*	949	17.30	180	6.57	204	7.72	336	7.70	720		740	7.39	1669	10.96
13. *Other individual factors, work conditions, and task characteristics that affect behavioral efficiency*	319	5.81	302	11.02	245	9.28	440	10.08	987		329	10.13	1306	8.57
14. *Training aids and devices and their use*	280	5.10	91	3.32	106	4.01	89	2.04	286		95	2.92	566	3.72
15. *Other areas of psychological research pertinent to human engineering*	170	3.10	33	1.20	41	1.55	43	0.99	117		39	1.20	287	1.88
TOTAL	5486	100.00	2740	100.01	2641	100.16	4364	100.01	9745		3248	99.99	15,231	99.99

* Prepared by Stanley Lippert, Douglas Aircraft.

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[1] Dr. Ezra Saul, Tufts University, has developed more recent information which suggests a considerably different distribution of topics.

[2] This figure does not reflect substantial amounts of pertinent literature published in non-English Journals and government reports.

More non-psychologists will enter the field and achieve positions of responsibility.

The medical profession will take more active roles in future space oriented programs.

More emphasis will be placed on developing better working tools and techniques.

More fundamental human factors research will be supported.

Human factors programs will gain more organizational stature within industry but at a less rapid rate than during the past several years.

Industry will begin demanding more concrete evidence from the field to be reassured that the work is truly productive, profitable and necessary.

The field will continue to retain its fluidity and lack of a clear cut image, and the transient nature of its specialists will not change for some time.

Other disciplines will increase their acceptance of the team contributions of human factors people and the field will begin to lose some of its mystical aura.

Human factors research will make significant contributions to man-in-space programs, teaching machine development and "thinking" machine technology.

Other fields will gain greater recognition either directly or indirectly from the activities of human factors research (e.g. bionics, bioinstrumentation, biotechnology, aerospace medicine).

FUTURE RESEARCH NEEDS

During the next several years there are, according to many human factors people, a number of areas which should receive much greater attention. Some examples are as follows:

Continued development of better human factors methodology.

Study of human tolerance to buffeting.

Development of practical life support requirements and equipment for space operation.

Expansion of behavioral research under stressful conditions.

Investigation of the effects of prolonged weightlessness.

Determination of the engineering properties of the human component in a system.

Extension of investigations on human perception, cognition, and motor response.

Determination of human decision-making capacities and limitations.

Development of techniques for applying learning theory to applied training problems.

Exploitation of man's capabilities in command-control systems.

Determination of psycho-social and personality dynamics of groups under variable and or prolonged stress.

Continued improvement of displays and controls.

OPERATING PROBLEMS

Despite, or as the result of, the rapid growth and success of human factors research, numerous operating problems have become apparent. According to key members of the field, the following problems need to be resolved:

Insufficient experimentally established data exist, or are being produced, to resolve many of the problems which human factors people must consider.

Communication between agencies and within the field must be vastly improved. Publication lags, overclassification of reports, and limited distribution of reports account for substantial communication delays. Although proprietary interests must be served, much of the material which is not proprietary is oftimes witheld partly because of the cost of distribution, but more frequently because of lethargy or selfishness. This artificial and generally needless restriction of useful material produced by industry is a

serious problem which can only be solved by people within the field.

Much valuable research time and many people are tied up in system or study proposal development, oftimes at the expense of constructive and vital research. There also is evidence of considerable duplication of agency requirements. Part of this problem could be resolved by much more concise statements in requests for proposals concerning what the agency actually expects to be produced in the human factors area. (It is encouraging to note that a task group on Human Factors Resources of the EIAA Human Factors Sub-committee (M–5.7) is making a thorough study of this problem and plans to develop useful guidelines for originators of electronics systems proposals which require human factors inputs).

Considerably more encouragement and support is needed for the basic or fundamental type research which is needed to provide the principles which we will need five to ten years hence.

Somewhere and somehow a clear and legally sound policy or statement must be developed concerning liability of private organizations conducting research with human subjects. Experiments which expose humans to the type of stresses expected to be encountered in high performance systems and in space vehicles are extremely risky. Industry and universities are understandably reluctant to engage in such research, regardless of its importance, because of the absence of national policy. Despite this, our nation's space program is moving rapidly toward exposing man to many of these stresses without adequate foreknowledge of the potential effects. An editorial appeared in the 14 October, 1960 edition of *Science* which discusses the problem of human experimentation and suggests a possible solution. It points out that prior consent of the subjects is not enough because in psychological research under extremes of stress the subject may very well not fully understand the dangers. A complete explanation of the nature or prospective results of such experimentation could vitiate the results. As contrasted with experiments with new medicines or operative techniques where the patients may directly benefit, the subjects of stressful psychological experiments may never benefit directly. The editorial suggests consideration of a partial solution mentioned in the 2 November, 1961 edition of *Duke Law Journal*, which proposes "liability without fault". Thus, if a subject is damaged as a result of participation in a psychological experiment he would be entitled to be "made whole", through treatment or rehabilitation or to receive compensatory damages. The subject, the experimenter, and the authorizing agency would have some protection. The experimenter would not be at fault, since he was acting in the interests of society. Thus society, through appropriate government channels, would assume the costs of rehabilitation or compensation just as society, through government channels, supports most of the experimentation for which the concepts of "liability without fault" would be appropriate.

This is, as stated, only a partial solution but one which is sorely needed in the quest for greater knowledge of man's reaction to stress and unusual environments.

CONCLUSION

In the foregoing material an attempt has been made to define and describe human factors research, to present historical milestones and organizational information, to suggest trends, to specify research needs, and to mention a few operating problems. Some limited conclusions have been made and some prognostication has been attempted.

If this material aids, even slightly, in updating knowledge of industrial human factors activity, if it pleases a few and irritates some, and if it stimulates someone to attempt to

prepare a more comprehensive paper, it will have been worth the author's effort.

What remains to conclude this paper and what was promised earlier is the list of current business and industrial human factors studies which appears in the subsequent pages (Appendix I).

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APPENDIX I

1961 LISTING OF HUMAN FACTORS RESEARCH ACTIVITY IN BUSINESS AND INDUSTRY

The following listing of human factors research studies in business and industry has been developed from responses to a 1960–61 survey of representative human factors programs. Although this list does not represent all of the responses received, it does include those companies who have specifically granted permission to have their activities listed in a publication.

The list includes human factors studies and related efforts being conducted by the respondents' organizations and, in some cases, studies or activities planned for the near future[1]. The material is presented in essentially the same form in which it was provided by the respondents:

AERONUTRONIC—A DIVISION OF FORD MOTOR COMPANY, NEWPORT BEACH, CALIFORNIA

Current

Human factors analysis, design and display of equipment for Tactical Operations Central project,

Development of comprehensive training and related simulation equipment for Tactical Operations Central project,

Research study of most favorable methods of topographic data presentation,

Other activities include research in data displays, simulation and automatic teaching devices, design of consoles and console displays, decision-making and management control, unit proficiency studies, information theory, communications, operations analysis, high-speed data processing techniques.

AEROTEC INDUSTRIES, GREENWICH, CONNECTICUT

Current

Development of helmet disconnects which reduce interference with head movement during flight.

Development of an air speed altitude warning switch for audible warning when aircraft descends below 10,000 ft and 210 knots and when landing gear has not been lowered.

AMERICAN INSTITUTE FOR RESEARCH, PITTSBURGH,

Current

Research on team training for guided missiles operation,

Development of personnel and training requirements for ASW Weapon System,

Determination of impact of new developments upon personnel systems,

Human factors support work for command and control systems (466L),

Human factors support research for the development of the Nike–Zeus system,

Research on learning theory implications for training device design,

Human factors support for the date processing subsystem of the SAC Control System,

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[1] A more detailed statement of the composition and activities of the Southern California companies appears in *Directory of Human Factors Groups in Southern California Area*, compiled by Dr. Thomas A. Hussman, Jr., and published by the Activities Committee of the Human Factors Society—Los Angeles Chapter.

Research on a handbook for preparation of job aids and guides,

Determination of observer responses in a vigilance task,

Research on a conceptual model for data flow,

Development of an index of operational complexity for electronic equipment,

Research on personnel requirements for the High Capacity Communications System (HICAPCOM),

Human factors support to GAM-887A weapon system development,

Evaluation of a prototype program of pilot-to-weather forecaster communications system,

Study of team communications, especially with regard to choice behavior,

Developmental study of a display for determining optimal means for presenting information for photogrammetric interpretations,

Study of visual signal conspicuity,

Development work on a self-programming computer,

Study of the use of a luminous panel inside refrigerators for directing attention to an internal door release mechanism.

Projected

Study of the relationship between the amount of available work space in maintenance job performance,

Development of a method for deriving training requirements task information,

Analysis of certain industrial tasks as a preliminary to establishing training,

Study of communication loops within the Mercury System,

Study of perceptual problems during zero-g.

APPLIED PSYCHOLOGY CORPORATION, ARLINGTON, VIRGINIA

Current

Visual collision avoidance research,

Development of design standards for man–machine tasks in Signal Corps systems,

Study of driver performance related to maintaining following distance while operating motor vehicles on highways,

Development of teaching aids for maintenance personnel,

Analysis of the future of the Aircar.

Studies of team performance.

AUTONETICS—A DIVISION OF NORTH AMERICAN INCORPORATED, DOWNEY, CALIFORNIA

Current

Human factors support work for advanced systems development,

Basic research in the field of Bionics.

AvCIR—A DIVISION OF FLIGHT SAFETY FOUNDATION, INC., PHOENIX, ARIZONA

Current

Crash injury research (human factors evaluations of preliminary designs, mock-ups, prototypes, and operational aircraft (including helicopter), from a crash-safety point of view),

Research on impact survival in air transport accidents (injuries are related to causative agents with attention focused upon occupant restraint, cabin environment, protective equipment, and emergency evacuation),

Determination of human engineering and crash-safety aspects of control and panel design in light planes,

Dynamic testing of aircraft and components (fully instrumented aircraft containing anthropomorphic dummies are crashed and the recorded impact data are related to design principles and survival limits of abrupt deceleration),

Human factor evaluations of transport and troop seats, litter installations, seat belt and harness installations, and crash helmets,

Statistical analyses of crash–injury relationships (includes analysis of the factorial structure of impact and damage variables, and the relation of tie-down effectiveness to injuries sustained in light plane accidents),

Study of the judgement of volume of complex irregular shapes from photographs.

AVCO—RESEARCH AND ADVANCED DEVELOPMENT, WILMINGTON, MASSACHUSETTS

Current

Study of operator performance as observed during the AN/GSN-11 radar air traffic control simulator factory acceptance,

Study of the effects of intermittent noise on radio communications to determine the optimum parameters for a communications jammer,

OSTP, OSVP, and MFTP exercises for the re-entry vehicle program of the Titan and Minuteman missile system (involves time-line and task-analysis exercises and analysis of equipment failure),

Human factors support for ICBM programs (activities involve study of man–machine operational requirements for and development of the R/V and associated GSE and TSE),

Application of human engineering design standards to company hardware items,

Human engineering analysis and studies to: define critical performance criteria; to confirm and/or determine suitable man–machine tradeoffs; to verify functional flows from the standpoint of personnel implications; to analyze operator input–output for determining display/controls, packaging and work place characteristics;

to investigate environmental and safety requirements,

Human engineering testing (as an integrated part of weapon system and re-entry vehicle system testing using AFBMD exhibit 60–1),

Failure analysis (the analysis of human induced failures and the generation of corrective action to satisfy the following three objectives: quality control of test procedures, training, incentive management, in the conducting of test programs; utilization of R and D test results in the improvement of operational equipment and procedures; operational system test data and improvement of operational equipment and procedures; operational system test data and improvement effort,

Studies in life support systems,

Operational and maintenance personnel requirements survey,

Mobile air traffic control system study,

Study of light as a deterrent weapon.

Projected

Advanced studies in life-space support systems.

Determination of human factors problems inherent in communication, missile and space systems projects.

BATTELLE MEMORIAL INSTITUTE, COLUMBUS, OHIO

Current

Development of automatic checkout procedures for space vehicles,

Development of a model to represent intervehicular communication,

Development of improved programming techniques for automated teaching,

Development of a human engineered microcard viewer,

Evaluation of the effects of electronic countermeasures on system performance,

Effects of levels of automation on human operators performance in man–machine systems,

Development of design criteria for intelligence display formats,

Development of an all aural reading device for the blind,

Validation of a psychological test battery to be used in the selection of research scientists.

BELL HELICOPTER COMPANY, FORT WORTH, TEXAS

Current

Research and development necessary to provide information displays which will enable all weather operation of helicopter (Army–Navy Instrumentation Program–Rotary Wing),

Research for development of altimeter displays (investigations concerned with establishing altitude information requirements, techniques for the evaluation of altimeter displays, and proposed designs of altimeter displays).

Projected

Study of the effects on operator performance of disturbance to the aircraft of the type experienced in low altitude high-speed flight or re-entry of an orbital vehicle,

Determination of the relationship between fidelity of simulation and transfer of training,

Determination of the contribution of angular rotations in pitch, roll, and yaw, and vertical motion in a simulator to transfer of training.

BELL TELEPHONE LABORATORIES, MURRAY HILL, NEW JERSEY

Current

Appearance and convenience studies of the design of telephone sets,

Studies of methods of subjective rating of transmission systems,

Studies of the effects on two-way conversations of relatively long transmission time such as might be encountered in communication in the earth satellites,

Studies of human factors aspects of storing, retrieving and handling telephone address information, (i.e. telephone numbers) (this includes studies on the ease of memorizing such telephone addresses, reduction of key or dialing time, and reduction of errors, retrieval of telephone addresses from directories, Information Operator or other storage media),

Studies of human factors aspects of switchboard design and switchboard operator functions,

Studies of maintenance problems in a telephone plant,

Studies of human factors and customer acceptance of new kinds of communication services.

BENDIX SYSTEMS DIVISION OF THE BENDIX CORPORATION, ANN ARBOR, MICHIGAN

Current

Study of man–machine problems associated with the development of the Eagle missile system (assisting in the design of the presentation and control sub-system of the Eagle missile system).

BENDIX CORPORATION, BENDIX RADIO DIVISION, BALTIMORE MARYLAND

Current

Development of controls and displays for electronically steerable array radar,

Development of controls and displays for communication system utilizing the satellite as a relay link,

Development of controls and displays for automatic remote tuning of aircraft electronic equipment,

Development of headgear to provide two-way radio communication for personnel on a flight deck of an aircraft carrier,

Development of an integrated control of a communication, navigation, and identification electronic equipment of a single or a two-place aircraft,

Study of human information rates including methods and criteria for evaluation of systems at the operator–display interface.

BOEING AIRPLANE COMPANY—AEROSPACE DIVISION, SEATTLE, WASHINGTON

Current

Space Medicine and Life Sciences Research and Development:

Definition of requirements for the capabilities of ecological systems and the biological components,

Definition of the biological effects of both long and short duration environmental variations occurring singly or in combination (the variant parameters include pressure, noise, heat, humidity, vibration, radiation, gravity, and atmospheric composition),

Research to define the requirements for protective equipment or devices that will allow man to operate effectively when subjected to the above normal variants as encountered normally or in emergency situations,

Determination of human limitations to heat, weightlessness, and vibration,

Determination of human metabolic and energy requirements in space,

Establishment of emergency procedures,

Establishment of provisions for launch site crews,

Definition of medical testing and physiological training requirements associated with the products of the division.

Determination of degradation products from cabin materials under space flight conditions,

Design and construction of miniature instruments for measuring respiratory rates, body temperature, electroencephalographic waves, electrocardiographic waves and heart sounds,

Study of human physiological problems in space flight,

Effects of radiation in space on man and his environment,

Development of respiratory support systems,

Development and evaluation of waste disposal systems suitable for use in advanced vehicles,

Determination of possible use of metabolic waste.

Human Engineering

Reconnaissance information processing; conduct of laboratory studies on display parameters, display-control systems, efficient methods for interpreting comparative cover, and basic form perception as related to training and display equipment requirements,

Function and task analysis leading to specifications of human engineering, man–machine systems and life support requirements,

Definition of escape, restraint and survival requirements for aircraft and manned space systems; evaluation of available and proposed systems,

Study and evaluation of manned air and space vehicle display and control systems, cockpit configurations and geometry,

Identification of biomechanic and anthropometric capabilities and limitations of man engaged in in-space and ground maintenance,

Conduct of laboratory studies on decision making,

Terrain avoidance display evaluation,

Evaluation of the effects of multiple stresses including vibration, heat, humidity, reduced atmosphere and oxygen on human performance and physiology,

Determination of the optimal utilization of the crew in manned space, air and missile systems,

Provisions of broad state-of-the-art and analytic human engineering and life support data to on-going projects.

BOEING AIRPLANE COMPANY, WICHITA, KANSAS

Current

Laboratory flight simulator evaluation of low-level pilot, navigation, and terrain avoidance problems and operational techniques,

Analysis of flight test to establish equipment requirements and evaluate effectiveness of fire control operator and system,

Analysis to establish need for, and define requirements for, ECM in-flight briefing display,

Analysis and laboratory flight simulator evaluation of aerial refueling techniques and procedures,

Laboratory experimental research to study the effect of low frequency vibration on human performance,

Analysis of laboratory simulator evaluation of operator and countermeasures equipment effectiveness in penetrating electromagnetic radiation environments,

General and specific task analyses to determine

optimum man–machine integration requirements for current and proposed weapon systems,

Studies of work station arrangements to satisfy the requirements established by task analyses.

Projected

Studies of the same general nature as those described above. Additional studies include investigation of color perception, eye-movement recording, and certain aspects of human fatigue,

Efforts will also be directed toward refining and devising more effective techniques for establishing optimum man–machine relationships in new systems concepts and designs.

BOSTROM RESEARCH LABORATORIES—DIVISION OF BOSTROM CORPORATION, MILWAUKEE, WISCONSIN

Current

Studies to determine the effects of vibration on human performance and physiological response,

Determination of the application of human engineering data to vehicular seat design,

Determination of the relative effects of noise and vibration on simple reaction time,

Determination of effects of human exposure to helicopter vibration,

Determination of the effects of tractor vibration on operator work performance.

COLLINS RADIO COMPANY, CEDAR RAPIDS, IOWA

Current

Development of new types of controls and displays for airborne equipment such as radio and autopilot devices.

CONVAIR—A DIVISION OF GENERAL DYNAMICS CORPORATION, SAN DIEGO, CALIFORNIA

CONVAIR ASTRONAUTICS DIVISION

Current

The Life Sciences Group is engaged in aerospace medical research, human factors engineering and life support engineering,

The Reliability Human Requirements Group activities include human engineering applications, man–space vehicle studies, maintainability analysis, mathematical model development, procedures analysis development, human error investigation, and system field evaluation,

The Personnel Subsystems Group is concerned with developing personnel subsystem information for the Atlas ICBM and advanced research on personnel sub-system problems concerned with SAMOS, Centaur, Minataur, Dyna Soar, Advent, APOLLO, SLOMAR, and Saturn.

CONVAIR—SAN DIEGO DIVISION

Current

The Human Factors Engineering Group activity includes human factors studies in the area of maintainability, anti-ballistic missiles system, supersonic aircraft, STOL, and manned space vehicles. A laboratory is maintained for evaluation of displays and measurement of psycho-physiological parameters of man–machine sub-systems.

COURTNEY & COMPANY, PHILADELPHIA, PENNSYLVANIA

Current

Study of escape and survival equipment in Naval aircraft (special emphasis on ejection seats and ejection philosophy of Naval aviators),

Development of color and lighting schemes for control spaces involving radar presentations,

Development of a technical information storage and retrieval system,

Studies of large industrial firm employee morale,

Design of patterns in operational analysis of product distribution for a large industrial firm,

Prediction of product acceptance,

Development of operational control of workloads in air traffic control,

Development of test and research designs in the operations of a major simulator,

Development of activity analyses among air traffic controllers,

Investigation of the psychological problems in space flight with emphasis on purely psychological aspects,

Study of the use and distribution of flight manuals,

Development of a model of a flight manual,

Study of non-programmed visual attachments to flight simulators,

Optimal use of simulation in aviation training,

Determination of human factors aspects of command and control systems.

DOUGLAS AIRCRAFT COMPANY AIRCRAFT DIVISION, LONGBEACH, CALIFORNIA

Current

Human factors coordination on new airplane designs,

Development of a bioelectronic monitoring console and bioelectronic sensing devices for monitoring human performance,

Studies of error feedback on compensatory displays using variable control and display sensitivity,

Performance studies of the relative advantages or disadvantages of a side stick control,

Development of improved horizontal situation displays,

Study of optimum classification and detection activity by visual and auditory displays with special electronic aids,

Coordination of Army–Navy Instrumentation Program human factors studies.

Projected

Investigation of the control accuracies attainable in each degree of freedom of control movement assuming that optimal information displays have been developed (includes a study of operator behavior as determined by sequential recording and eye-movement analysis),

Studies of physiological, psycho-physical and performance in a variable parameter control simulator to determine the nature of proprioceptive information and its interaction with other sense modalities,

Determination of the optimum control system characteristics for the Army–Navy Instrumentation Program display configuration for specific vehicle classes and modes of operations,

Determination of optimum design values in television or raster scan display mechanization.

Study of terrain avoidance procedures using simulation techniques and determination of optimum presentation of information,

Studies of the path or command director requirements for specific classes of vehicles.

DOUGLAS—SANTA MONICA DIVISION, SANTA MONICA, CALIFORNIA

Current

Development of equipment maintainability design evaluation instrument,

Development of the display panel design for a Nike–Zeus test console,

Determination of the effects of weapons (biological, chemical and radiological),

Determination of the systems and equipment design requirements, the areas of communication of human data processing, computer simulation and biological systems, design for maintenance, design of training equipment and simulators,

Basic and applied research in life sciences including human factors space biology, "extra-terrestrial life" and "origin of life", space medicine, toxicology, bionics, human behavior, human simulation, biostatistics, and radiobiology,

Determination of use of eye camera to measure advertising copy.

FAIRCHILD STRATOS CORPORATION—ELECTRONICS SYSTEM DIVISION, LONG ISLAND, NEW YORK

Current

Development of human factors requirements for: a surveillance drone weapon system, a radar training device, a visual landing system device, a tracking radar system, a fire control system, and communication system,

Development of a visual simulator SMK–22/F37 A–T Trainer Attachment.

FRANKLIN INSTITUTE, PHILADELPHIA, PENNSYLVANIA

Current

Analysis of command and control problems,

Study of communication techniques and the administrative processing of information in a large Army headquarters,

Study of decision making by man and computer,

Determination of human factors aspects of air traffic control,

Automatization of communications facility,

Selection and specification of new criteria for skill development (the study of mathematical models for human behavior),

Investigation of human control dynamics,

Development of displays for individual and group decision.

GARRETT CORPORATION—AIRESEARCH MANUFACTURING COMPANY, LOS ANGELES, CALIFORNIA

Current

Determination of life support requirements for manned space vehicles,

Development of life support and atmospheric control systems.

GENERAL ELECTRIC COMPANY

G.E. LABORATORY, SCHENECTADY, NEW YORK

Current

Design of maintenance and automatic checkout systems,

Evaluation of programmed learning materials and devices,

Study of the psychophysics of control knob "feel".

G.E.—DEFENSE ELECTRONIC DIVISION, LMED, ADVANCED ELECTRONICS CENTER, ITHACA, NEW YORK

Current

Development of an optical method for presenting a revolving CRT sweep as a stable horizontal line,

Identification of a sensitive and reliable behavioral measure of ion effects and development of techniques to control experimentally interacting variables,

Study of the ear as a transducer of certain types of modulated RF energy,

Experimental investigation to determine detectability of various colored signals against various amounts of colored background noise,

Exploration of the behavioral effects of RF irradiation of monkeys,

Study of radar operator detection thresholds for three interface variables (ambient illumination, CRT trace brightness, video amplifier gain),

Study of crew loading for airborne and ground radar operators (to determine sensitive task areas and to develop operating procedures),

Development of design philosophy for display and controls for a missile tracker,

Estimation of time to collision (measurements made of adequacy with which subjects could use like contact analog-like grid display in predicting time to impact with ground),

Measurement of control action time and variability (developed method for determining time required to grasp and operate simple controls),

Development and test of coding concepts to integrate information for pilots (Army–Navy Instrumentation Program),

Establishment of design considerations for maintaining AEW electronics equipment for maximum reliability,

Global Surveillance System human factors studies, Phases I and II,

Study of TV image enhancement.

Projected

Basic and applied research in the area of bionics, including adaptive machines, unique sensors, biomedical technology, and environmental effects.

G.E.—DEFENSE ELECTRONIC DIVISION, SYRACUSE, NEW YORK

Current

Field validation of a simulator test of electronic system trouble shooting proficiency,

A comparative study of humans and pattern recognizing machines in sonar target classification.

Projected

The quantification of variables of technical manual quality,

An investigation of the problem of flash blindness in weapon system personnel,

A study of information requirements in methods of presentation in Tactical Command/Control systems,

A study of the relationships between characteristics of complex electronic systems and downtime for repair.

G.E.—INFORMATION SYSTEM SECTION, WASHINGTON, D.C.

Current

Development of the Perceptron,

An experimental design for key word coding,

Development of effective methods for presenting information on large scale displays,

Developmental work on intelligent machines.

GOODYEAR AIRCRAFT CORPORATION, AKRON, OHIO

Current

Development of a mathematical model for describing two dimensional displays.

Empirical research on the human adaptive response mechanism,

Display determinants for adequate perceptual motor response,

Studies on the relationship between perceptual closure and cff,

Stimulus material-determinants,

Human operator reliability models (theoretical),

Human factors-Subroc fire control console,

Bioastronautics: Development of an inexpensive biopack,

Development of engineering description of the humans' sensory functions and derivation of an analog computer model,

Derivation of a theoretical model for the humans' perceptual mechanism,

Experimental studies in the area of target identification and detection,

Experimental–theoretical studies of humans' cognitive functions,

Development of a theoretical–experimental model of human operator's capability for adaptive perceptual motor response in a closed loop system,

Determination of effects of environmental variables upon animal anatomical structure and physiological function as well as performance,

Investigations in the general areas of cell motility.

GRUMMAN AIRCRAFT ENGINEERING CORPORATION, BETHPAGE, LONG ISLAND, NEW YORK

Current

Analytical studies concerned with mission and function analysis in order to specify task allocation, work space layout, lighting, noise, safety, and the like for manned spacecraft,

Compilation of life support requirements for manned spacecraft,

Analytical investigations of methods and means of precision control of the attitude of earth satellites from ground stations,

Preliminary experimental (simulator) studies to determine the specifications for/and effectiveness of satellite mounted television pick-ups for stellar observations,

Analytical investigations to develop mission and functions analysis, function location, timeline studies, and personnel requirement studies of novel airborne ASW systems,

Derivation of human speed and accuracy performance data for use in a study comparing the effectiveness of three ASW computer display systems,

Establishment of optimum location of the control panel for an ASW computer–display equipment,

Evaluation of commercially available lenticular devices as to size, legibility, and maintainability,

Studies of crew loading, CIC compartment lighting, radar scope symbology, and crew use of standard cockpit equipment,

Determination of CRT symbols for display of navigation information,

Control panel layout including positioning of control displays, lettering and labeling, lighting requirements and techniques for Naval aircraft,

Determination of visual problems resulting from use of equipment under conditions of high ambient illumination,

An experimental study to evaluate pilot performance during a low level attack run in clear air turbulent environments (study used motion simulator incorporating representative aircraft dynamics and ambient environment),

Determination of pilot steering and altitude error as a function of command heading and altitude scale factors on the Kaiser Electronic Analog display,

Analysis to determine the physiological effects of rapid decompression resulting from canopy and windshield failures at various altitudes,

Analytical studies of airborne visual battlefield surveillance,

An analysis of crew activities in the operation and maintenance of the MK4 full pressure suit as related to the design of the ready room facility for the Navy,

Analysis of subjective and performance reactions to vibration as applied to hydrofoil seacraft design,

Study to determine the effect of seat geometry and cushioning on operator efficiency during extended periods,

Experimental study to determine if there is any measureable difference in behavior attributed to a difference in the polarity of an ionized environment,

Design and evaluation of a disposable oxygen mask and bottle for passenger utilization in the event of decompression,

Evaluation of an energy absorbent system to decrease the acceleration forces on the occupant during a controlled crash or arrested landing,

Evaluation of a restraint system that protects the pilot against submarining and porpoising as well as reducing the accelerated forces on the pilot during controlled crashes and accelerated landings and ejections.

Projected

Studies will be carried out in a fixed base reentry flight simulator to determine information inputs, display and control configuration for hyperbolic re-entry,

Experimental studies are planned of aided, quickened, and final value control display systems as applicable to manned spacecraft,

Analytical and experimental studies are planned of the control of lunar and planetary automotive vehicles from earth by means of TV and radio links,

Study programs are planned leading to life support system design requirements including contamination and decontamination, urine purification and in-flight feeding,

A study is planned to determine the feasibility of using a ground based Mercator projection of the celestial sphere in conjunction with the system of projected images for displaying accurately the line-of-sight of the orbiting astronautical observatory,

A study is planned to determine human control capability in high sea states in fully submerged foil seacraft.

HUGHES AIRCRAFT COMPANY HUGHES—ENGINEERING DIVISION, CULVER CITY, CALIFORNIA (AEROSPACE GROUP)

Current

Analysis and simulation of interceptor fire control manual steering dynamics,

Functional design of a long-range interceptor fire control and navigation display and control system,

Analysis, experimentation and functional design of operator performance requirements in a Tactical Strike System,

Analysis and functional design of operator performance requirements in airborne anti-submarine warfare and control/display sub-system design,

Development and experimental evaluation of advanced radar and infrared display techniques,

Development and experimental evaluation of high speed, low altitude terrain avoidance display sub-systems,

Analysis and functional design of display and control requirements and sub-system design for the APOLLO, Earth and Moon orbiting manned space vehicles,

Determination of human engineering requirements in the rotational and translational control and the navigation of manned orbital vehicles,

Establishment of human factors requirements in the operation and maintenance of nuclear powered systems,

Establishment of human engineering requirements in the remote control of the mission functions for unmanned Surveyor lunar soft landing vehicle.

HUGHES—GROUND SYSTEMS GROUP, FULLERTON, CALIFORNIA

Current

Studies of complex decision making (as exemplified by threat evaluation),

Design and development of special displays for command and control system application,

Human factors requirements established for command and control and information systems,

General and specific studies of data pick-offs,

Visual studies concerned with information capacity of the eye.

HUGHES RESEARCH LABORATORIES, MALIBU, CALIFORNIA

Current

Experimental study of the man's ability to detect, discriminate, learn, recall and respond at several suboptimum levels of alertness,

Study of task and environmental factors which lead to a reduction in the man's alertness level,

Determination of physiological measures other than the EEG which will predict a reduction in alertness and in performance capability.

HRB-SINGER, INC.—A SUBSIDIARY OF THE SINGER MFG. COMPANY, SCIENCE PARK, STATE COLLEGE, PENNSYLVANIA

Current

Determination of the information presentation requirements of human data processing roles in future aerospace surveillance systems,

Generation of training principles for optimizing the human operator's ability to perform efficiently in multi-task situations under high levels of speed and load stresses,

Determination of methods for evaluating printed advertisements,

Design and evaluation of a mobile air traffic control system,

Construction and examination of the validity of specific models of driver performance.

INTERNATIONAL BUSINESS MACHINES CORPORATION (FEDERAL SYSTEMS DIVISION, OWEGO, NEW YORK: PRODUCT DEVELOPMENT LABORATORY, POUGHKEEPSIE, NEW YORK: RESEARCH CENTER, YORKTOWN HEIGHTS, NEW YORK)

Current

The following studies are being conducted in the listed divisions:

Image quality research,

Human vehicle control simulation,

Display evaluation,

Programmed teaching,

Personnel data processing,

System operator simulation,

Legibility of Alpha-Numeric presentations on CRT displays,

Methods of utilizing color for displays,

Accuracy of transcribing verbal material,

Evaluation of manual input devices for speed and error rates,

Visual perception relating to varying dimensions and visual angle.

INFORMATION TECHNOLOGY LABORATORIES, LEXINGTON, MASSACHUSETTS

Current

An evaluation of integrated open-loop educational television and programmed (teaching machine) instruction,

Development of automated training of mail order clerks,

Development of a mathematical analysis of inherent human search behavior.

INTERNATIONAL ELECTRIC CORPORATION, PARAMUS, NEW JERSEY

Current

Specification of operational requirements to permit project control and development of computer programs and personnel procedures prior to installation and operation of field systems.

Personnel subsystems studies of command and control systems.

ITT FEDERAL LABORATORIES, NUTLEY, NEW JERSEY

Current

Development of electronic data traffic control subsystem for SAC Control System,

Development of sonar training programs and training devices,

Development of integrated communication systems for nuclear submarines,

Development of three-dimensional display techniques,

Determination of role response economy in human operant behavior.

FORD MOTOR COMPANY, DEARBORN, MICHIGAN

Current

Establishment of design standards for land vehicles, particularly passenger car, with current activities in the areas of vehicle glazing design, seating comfort, and vehicle steering,

Establishing a relationship between human dynamic visual acuity and the glass surface geometric parameters,

Optimization of the match between the capabilities and limitations of the human driver and the vehicle dynamic performance.

LEAR, INC., GRAND RAPIDS, MICHIGAN

Current

Development of a design procedure which attempts to integrate human factors considerations within a systems engineering approach to cockpit design,

Determining operator information requirements directly from an analytic expression of a system,

Determining operator control effectiveness during re-entry as a function of displays,

Determining operator attitude control effectiveness in orbit as a function of displays, vehicle configuration and type of control system,

Development of display designs for specific individual instruments for new aircraft and space vehicles,

Studying the functional relationships between crew members and the controls and displays of ASW aircraft equipment.

LINK DIVISION OF GENERAL PRECISION, INC., BINGHAMTON, NEW YORK

Current

Determination of problems inherent in space training, space instrumentation, space simulation, and human performance stress,

Development of methods for automatic programming, automatic monitoring, automatic scoring, and automatic recording for simulators and other special training devices,

Development of the Link Intellectual Functions Tester and a set of test designs for use in measuring and studying intellectual ability for man under high-g conditions,

Comparison of methods or devices used in operator training,

Development of military industrial and educational training programs,

Development of manuals of instructions and handbooks,

Investigation of methods of warning including collision avoidance techniques,

Determination of communications problems including forms of information methods, presentation rate and the like.

LOCKHEED AIRCRAFT CORPORATION

CALIFORNIA COMPANY, BURBANK, CALIFORNIA

Current

Activities within the Aeromedical, Human Engineering, Spacecraft Engineering and Psycho-Physics organizations include:

Development of spacecraft simulators,

Development of supersonic escape capsule,

Development and testing of the Jetstar oxygen system,

Studies of cockpit requirements for supersonic transport,

Studies of decompression events,

Development of spacecraft life support requirements,

Studies of annoyance effects of noise,

Studies of effects of noise on intelligibility of communication,

Studies in information handling,

Studies of the physiological and communicative aspect of porpoise sound production,

Laboratory investigation of effects of negative ions on human operator behavior,

Determination of human factors requirements for SLOMAR-SMART space vehicles.

GEORGIA COMPANY, MARIETTA, GEORGIA

Current

Laboratory studies of small group task performance,

Human factors studies in the design of flight stations for advanced cargo aircraft and other airborne systems,

Survey of human factors associated with high speed, low altitude flight.

Investigation of human response to simulated weightlessness (Null Gravity Simulator project),

Development of advanced techniques for measuring the electrical activity of the brain,

Determination of optimum work–rest schedules for advanced systems crews on extended missions,

Psycho-social and personality dynamics of small groups under prolonged stress.

MISSILES AND SPACE COMPANY, SUNNYVALE, PALO ALTO AND VAN NUYS, CALIFORNIA

Current

Establishment of functions and responsibilities of personnel sub-systems,

Development of display and control requirements for Satellite Systems and Polaris Missiles System,

Monitoring the design of Polaris missiles and ground support equipment to assure compatibility with human requirements.

LOCKHEED MISSILES AND SPACE COMPANY, SUNNYVALE, PALO ALTO AND VAN NUYS, CALIFORNIA

Current

This list reflects activities of the following groups: Space Systems; Personnel Subsystems; Polaris Human Engineering; Biomedical Department; Advanced Systems Research—Human Factors Staff; Life Support Engineering; Aerospace Medicine:

Establishment of functions and responsibilities of personnel subsystems,

Development of display and control requirements for Satellite Systems and Polaris Missiles System,

Computer programming of inputs to selected consoles to study operator performance, measure proficiency, and for the provision of training,

Design of simulators for training and measurement of crew functions in command and control systems,

Development of objective methodologies and instrumentation to measure operator performance during actual operations,

Design of training equipment to provide maintenance training and operator training,

Task and procedures analysis to determine allocation of functions by job speciality,

Analysis of specific operator functions to determine critical aptitudes involved which must be incorporated into selection criteria,

Provide personnel planning information to determine optimal organizational control procedures, channelizing of communication, and command direction,

Analysis of new systems to determine functions requiring automation and critical operations requiring manual procedures,

Test and evaluation of personnel performance during actual operations to identify new requirements or changes in human engineering, training, procedures and personnel planning,

Development of proficiency standards for critical operator functions; determination of parameters on which standards of performance should be established,

Development of unit proficiency systems for determining unit readiness, and identifying training requirements which leads to developing statistical indices of readiness,

Monitoring the design of Polaris missiles and ground support equipment to assure compatibility with human requirements,

Determination of components of missiles systems which under normal or abnormal conditions may be toxic or generate toxic materials,

Determination of human requirements for lunar operations,

Development of an Advanced Biomedical Capsule (ABC) for study of primates in space,

Evaluation of procedures of preparation and launch of missiles to ascertain man–machine operating problems,

Identification and description in terms of design and utilization of equipment required for technical training, human engineering, and personnel evaluation,

Determination of life-support requirements and human factors problems associated with man-space vehicles,

Determination of human factors problems and cockpit design requirements for tactical air-to-surface missiles system,

Specification of operator requirements for multimanned space stations,

Experimental evaluation of algae for use in closed ecological systems,

Development of implantation techniques for bioelectric monitoring,

Evaluation of biomedical measurement techniques,

Development of life support systems for biomedical capsules,

Analytical study of man's utility in space.

Determination of components of missiles systems which under normal or abnormal conditions may be toxic or generate toxic materials,

Development of an Advanced Biomedical Capsule (ABC) for study of primates in space,

Evaluation of procedures of preparation and launch of missiles to ascertain man–machine operating problems,

Identification and description in terms of design and utilization of equipment required for technical training, human engineering, and personnel evaluation,

Determination of life support requirements

and human factors problems associated with man–space vehicles,

Determination of human factors problems and cockpit design requirements for tactical-air-to-surface missiles system,

Specification of operator requirements for multi-manned space stations,

Experimental evaluation of algae for use in closed ecological systems,

Development of implantation techniques for bioelectric monitoring,

Evaluation of Biomedical Measurement Techniques and data compression,

Development of life support systems for biomedical capsules,

Analytical study of man's utility in space.

McDONNELL AIRCRAFT CORPORATION, ST. LOUIS, MISSOURI

Current

Development of advanced displays of tactical decision makers,

Analysis of the decision making functions of man in a space vehicle,

Definition of the Mercury astronaut's task along with specific estimates of the probability that such tasks can be performed,

Testing of a closed environmental system with human subjects,

Experimental studies of vision within and outside the Mercury capsule,

Simulator studies of pilot's capabilities to perform control functions,

Task analysis for aircraft and space systems such as MTSS and STOL.

MARTIN COMPANY, ORLANDO, FLORIDA

Current

Study of man's ability to assimilate information and the rate at which he can assimilate same (determination of bit capacity in relation to various types of inputs and outputs),

Study to determine quantitative values for parameters in complex displays, including type of symbology, size of symbols, brightness–contrast ratios, resolution, ambient illumination, flicker, target detection, target identification, and display size.

MAUCH LABORATORIES, INC., DAYTON, OHIO

Current

Development of an omni-environmental space suit for the Air Force,

Development of a reading machine for the blind for the Veteran's Administration,

Development of advanced type prostheses for the National Academy of Science.

MELPAR, INC., FALLS CHURCH, VIRGINIA

Current

Study of Alpha-numeric displays for commercial and military application,

Design and evaluation of visual displays for use in determining the identity of underwater objects,

Establishment of human factors requirements for the design and development of ground data handling equipment,

Determination of human factors requirements for the design of ground support equipment,

Studies of methods and equipment for monitoring and scoring missile crew performance,

Establishing human factors requirements for the design of visual simulation equipment.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY—DYNAMIC ANALYSIS AND CONTROL LABORATORY, CAMBRIDGE, MASSACHUSETTS

Current

Experimental investigation of the adaptive control characteristics of the human operator,

Determination of human hill-climbing ability,

Determination of automobile driver alertness,

Establishment of feedback in remote manipulation,

Development of mobility devices for the blind.

NEW YORK UNIVERSITY, COLLEGE OF ENGINEERING, NEW YORK

Current

Development of mathematical models for such physiological quantities as skeletal muscles and patterns of movement,

Determination of skeletal muscular resistance to shock loads of certain segments of the body,

Development of prosthetic equipment based on human engineering principles.

NORTH AMERICAN AVIATION, INC., LOS ANGELES DIVISION, LOS ANGELES, CALIFORNIA

Current

Studies in the flight simulation laboratory involved with describing human transfer function and isolation of variables affecting the transfer function such as controlled dynamics, motion and acceleration, task variables, and inter and intra individual variations,

Investigation of recognition and interpretation capabilities under various conditions of resolution, obstruction, and task loading (terrain avoidance, landing, navigation and target detection are the primary modes being investigated),

Studies of the command decision response contingencies associated with the on-board command task of aerospace vehicle (in particular, techniques for rapid reprogramming to decision making and data processing aids are being investigated),

System analysis of human factors problems in advanced atmospheric vehicles both commercial and military,

Investigation of information displays and general flight controls.

PHILCO CORPORATION WESTERN DEVELOPMENT LABORATORIES, PALO ALTO, CALIFORNIA

Current

Speech intelligibility studies (psycho-physical studies are being conducted which use the intelligibility of speech as the criterion for the optimization of design parameters in FM phase lock-loop receivers when these receivers are to be used primarily in speech communication. The independent variable is carrier to noise ratio at the receiver input. The dependent variable is per cent intelligibility of transmitted speech. Study parameters include: loop bandwidth, carrier deviation ratio, carrier drift from nominal center frequency, limiter design, output audio bandwidth,

Satellite detection studies (identification and specification of signals received from artificial earth satellites which are known not to be actively radiating electromagnetic energy),

Component evaluation studies (determination of the suitability of control and display components for use in equipment design),

Personnel subsystems research on operational system reliability.

PSYCHOLOGICAL RESEARCH ASSOCIATES—A DIVISION OF THE MATRIX CORPORATION, ARLINGTON, VIRGINIA

Current

Feasibility study of a recovery control center (specification of requirements for biomedical instrumentation facilities, medical debriefing areas and examining rooms and the like for a space vehicle recovery center),

Human factors studies in the Titan Guidance System (includes the development of personnel data in accordance with BMD exhibits, development of training equipment recommendations, specification of maintenance readout points throughout the guidance system and for general human factors inputs of a human engineering nature,

Development of human factors inputs for designs of space vehicles,

Development of design recommendations for a complex undersea warfare coordinated tactics trainer.

PURDUE UNIVERSITY DEPARTMENT OF PSYCHOLOGY, LAFAYETTE, INDIANA

Current

Determination of the use of auditory cues as aids in visual monitoring tasks (study deals with the use of various types of auditory cues),

Determination of frequency intensity duration and direction (in directing visual attention to certain special areas),

Determination of display arrangement, number of channels and information speed as related to operator performance,

Determination of the effects of delayed feedback in a tracking operation.

RCA—DEFENSE ELECTRONIC PRODUCTS, WASHINGTON, D.C.

RCA—MAJOR DEFENSE SYSTEMS DIVISION, MORRESTOWN, NEW JERSEY

Current

Design and development of large systems (e.g. Talos, Atlas, BMEWS),

Development of functional requirements, allocation of functions among operators and equipment, analysis of information flow, prediction of overload probabilities,

Studies of man–machine interface requirements, selection and design of components, development of panel layout logic, modularization of console sub-assemblies,

Design of operations centers, including training facilities,

Specification of environmental characteristics,

Design of protective systems for handling hazardous material,

Design of field evaluations and operational experiments,

Experiments on visual presentation of information.

RCA—AEROSPACE COMMUNICATIONS AND CONTROLS DIVISION, CAMDEN, NEW JERSEY

Current

Research in bionics and automated instruction,

Design of operator and maintenance stations for missile systems,

Development of life support and closed ecological systems,

Development of micro-miniaturized personal telemeters for measuring EKG, EEG, etc.; Development of inter-planetary life-probe systems.

RCA—AEROSPACE COMMUNICATIONS AND CONTROLS DIVISION, BURLINGTON, MASS.

Current

Design of airborne weapon control systems,

Analytic studies of missions, operator tasks, information requirements,

Research on environmental effects, visual displays,

Design and experimentation on automatic training devices,

Simulation studies of aerospace control systems and proposed space rendezvous techniques,

Development of training techniques for Bullpup, B-70, and Dyna Soar programs.

RCA—SURFACE COMMUNICATIONS, CAMDEN, NEW JERSEY

Current

Provide design review services,

Conduct job analysis studies,

Conduct morale and motivation research in connection with a "White Room" assembly facility.

RCA—DATA SYSTEMS DIVISION, VAN NUYS, CALIFORNIA

Current

Perform analytic studies of image interpretation of meteorological data from Tiros satellites,

Conduct operations analysis of all portions of down-range nose cone tracking ship,

Design and testing of console for intelligence analyst task,

Design of displays for world-wide communications agency,

Conduct systems studies for national bomb alarm and damage assessment,

Design of mobile automatic programmed checkout equipment for Atlas,

Design of launch complex for Saturn; research on color coding of displays,

Development of automatic information storage and retrieval systems,

Perform analysis of human factors aspects of a lunar-based control center.

REPUBLIC AVIATION CORPORATION, FARMINGDALE, LONG ISLAND, NEW YORK

Current

Studies of design requirements and life support systems for manned aerospace vehicles,

Studies of biomedical data systems which will sense, transmit and record pertinent indications of man's psychological and physiological integrity,

Studies of requirements for protective devices and garments,

Studies of man's tolerance to specific hazards such as weightlessness, rotation and vibration,

Studies to determine closed ecological systems for balancing the respiratory and nutritional requirements of man.

RITCHIE AND ASSOCIATES, INC., DAYTON, OHIO

Current

Study of cockpit design and methodology,

Study of man–machine systems of the APOLLO vehicle which includes allocation of functions between man and machines, allocation of functions between crew members, specification of information requirements, and cockpit design,

Study of time-based analyses of crew functions and weapon systems (this involves the survey of some industry techniques, and analysis and synthesis).

SIERRA ENGINEERING COMPANY, SIERRA MADRE, CALIFORNIA

Current

Specification of human factors requirements as they pertain to product development,

Human factors studies related to the man–machine aspects of supplementary oxygen breathing equipment and safety devices.

SPACE LABS. INC., VAN NUYS, CALIFORNIA

Current

Development of biological telemetering techniques,

Development of physiological data acquisition systems,

Development of a sanitation and personal hygiene system suitable for use under zero-g.

STANFORD RESEARCH INSTITUTE—DIVISION OF ECONOMICS RESEARCH, MENLO PARK, CALIFORNIA

Current

Development and evaluation of techniques and methods for dealing with human contributions to reliability and weapon systems operations,

Development of a technique for analytically determining weapon system functions and operations to be performed by man,

Development of a method for performing human engineering analyses of missile systems.

Projected

Development and application of means for evaluating man–machine sub-systems,

Evaluation of three-dimensional displays,

Determination of changes in behavioral responses associated with the use of psychopharmacological drugs.

SYSTEM DEVELOPMENT CORPORATION, SANTA MONICA, CALIFORNIA

Current

Development of task analysis and criteria for evaluation of battle staff functions to determine the kinds of summary display and battle staff needs for fulfilling its functions,

Investigation of the factors and attitudes towards machines and man–machine relationship,

Operator loading study of the SAGE missile intercept director–technician position to identify problems for program design purposes,

Investigation, involving war gaming techniques, of the equipment and personnel which can be expected to survive and be available for control of interception following an attack,

Decision processes research (e.g.), studies of: Communication networks and group tasks; Decision making in structured groups; Human data Processing Behavior; Behavior in large government, military and industrial organizations—Project LEVIATHAN,

Development of a program to train the system in an electronic countermeasure environment, stressing electronic counter-countermeasures, activities and procedures,

Automated teaching research,

Development of a program of on-and-off computer evaluation and training of SAGE weapons personnel at both the subsystem and operator levels,

Studies of information retrieval systems,

Development of a subsystem evaluation training program for SAGE air surveillance crews,

Research in intelligence-system decision making,

Development of an improved SAGE system training program which will exercise the system under heavier loads,

Development of procedures for training of battle and support staffs in combat and direction centers,

Development of equipment procedures for equipment requirements and procedures for systems training under communications jamming conditions,

Development of techniques to increase the flexibility of training problems by additions or replacements of parts of problems,

Development of computer programs to exploit computer potential for system training and automatic proficiency evaluation of system performance,

Determination of principles of training problem design and simulation requirements,

Description and analysis of other air defense command and control systems in order to evaluate their possible effects on the SAGE and Air Defense Systems and/or to identify training requirements and prepare training plans for these other systems,

Compilation of a survey of communications display, and control equipment and procedures at long range radar sites developing recommendations for optimal arrangements,

Development of a method for exploiting the visual capabilities of radar operators in order to improve the filtering of radar inputs by means of human intervention before computer processing,

Development of methods of task equipment analysis in order to provide more systematic description of equipment and related tasks.

SYSTEM DEVELOPMENT CORPORATION—COMMAND CONTROL DIVISION, PARAMUS, NEW JERSEY

Current

Development of operational requirements for the Strategic Air Command Control System,

Design and development of Strategic Air Command Control System displays,

System design validation for the Strategic Air Command Control System through operation of a simulation facility,

Development of system training requirements for the Strategic Air Command Control System,

Development of system operational requirements for the NORAD COC,

Development of training requirements for the NORAD COC.

TULANE UNIVERSITY—DEPARTMENT OF PSYCHOLOGY, NEW ORLEANS, LOUISIANA

Current

A series of studies are being conducted covering the long term retention of motor and verbal skills.

UNIVERSITY OF CALIFORNIA, INSTITUTE OF TRANSPORTATION AND TRAFFIC ENGINEERING, LOS ANGELES, CALIFORNIA

Current

An engineering study of factors associated with accidental collision of automobiles with the aim of reducing and, where possible, eliminating bodily injury,

Determination of car interior revision for collision injury reduction,

Development and evaluation of special devices for infant and child protection from impact or emergency braking situations,

Optimization of automobile collision performance through structural revisions which include the application of low density, high strength materials,

Determination and evaluation of means for delethalising the automobile front end with respect to pedestrian accident.

VOUGHT AERONAUTICS—A DIVISION OF CHANCE-VOUGHT CORPORATION, DALLAS, TEXAS

Current

Development of all weather displays, cockpit configurations, simulator studies, and crash survival techniques for VTOL aircrafts,

Development of human factors criteria for nuclear ground handling, remote handling and training aids,

Development of the state-of-the-art advances and continuous improvement of ground support procedures.

WESTGATE LABORATORY, INC., YELLOW SPRINGS, OHIO

Current

Conversion of a flight attitude indicator to a projection system (this modified instrument is mounted behind the pilot and projects an artificial horizon onto the windshield),

Development of a highly sensitive electronic differential pressure gauge for use in detecting tiny pin-hole leaks in food cans, hermetically sealed containers, refrigeration systems and like,

Development of plans for human factors study of radar, target pattern recognition,

Development of a line of eye movement recording cameras for use in airborne and ground environments. One type of camera gives direct readout of the observer's region of regard in the form of a spot superimposed on the image of the scene; playback is in motion picture format. The other type of camera gives analog voltages in X and Y corresponding to instantaneous eye movements.

WESTINGHOUSE ELECTRIC CORPORATION—AIR ARM DIVISION, BALTIMORE, MARYLAND

Current

Studies of tracking as related to interceptor fire control systems,

Study of relationship between hue of adapting stimulus and dark adaptation.

LIFE SCIENCES RESEARCH PROJECTS

(Developed by the Life Sciences Committee of the Aerospace Medical Association and provided by Dr. James N. Waggoner, Chairman.)

The following list of life sciences studies identifies the activities with the organizations currently active in the listed area:

Study Area	Organizations Sponsoring Investigations
Human limitations to cold	Albany Medical College
Human limitations to heat	Albany Medical College Convair Astronautics University of California at Los Angeles Haskell Laboratories (Du Pont)
Human limitations to oxygen-rich atmospheres	University of Rochester Bryn Mawr College University of Pennsylvania University of Illinois, Aeromedical Laboratory
Human limitations to various CO_2 partial pressures	Lovelace Foundation University of Pennsylvania

Study Area	Organizations Sponsoring Investigations
Human limitations to all other possible air constituents	Southwest Research Institute The Garrett Corporation Lockheed California Co., Burbank Convair Astronautics General Electric
Human limitations to acceleration	Mayo Clinic, Rochester, Minnesota
Weightlessness	(Almost all work being done by governmental agencies) Lockheed Georgia Company, Marietta
Ionizing radiation and neutrons (for crews, but also ground support, depending on fuel used)	Yale University University of Texas University of California at Berkeley Florida State University The Garrett Corporation Brown University Los Alamos Laboratory, New Mexico
Non-ionizing radiations	Douglas Aircraft, Santa Monica Convair, San Diego
Human limitations on exposure to high sound pressure levels	(Almost all work being done by governmental agencies)
Human limitations to various vibrations	Ohio State University
Human metabolic and energy requirements in space	The Garrett Corporation
Methods of providing for human needs in prolonged space flights	Chance-Vought (Dallas) Mississippi State University General Electric Company American Machine and Foundry Company Minneapolis-Honeywell Electric Boat Division of General Dynamics Corporation The Martin Company (Denver) Boeing Airplane Company MSA Research Company Firewel Company, Inc. University of Texas New York University Southwest Research Institute RIAS, Inc. Space Technology Laboratories The Garrett Corporation Northrop Corporation (Norair Division) Lockheed Georgia Co. Lockheed Missiles and Space Co.
Drug or other artificial methods (e.g. Hypnosis) of increasing tolerance or decreasing needs	Northwestern University Lockheed Georgia Co. Douglas Aircraft (Santa Monica)
Human tolerance to various odors	Southwest Research Institute
Capabilities for combating illness in space	Lockheed California Co. The Garrett Corporation
Ability to eliminate disorientation or vertigo	Temple University Convair Astronautics
Consideration of psychologic adversities due to space flight	Lockheed Georgia Co. Vought Astronautics (Dallas)
Provisions for all emergencies ("Environmental criteria for escape")	North American Aviation, Inc. McDonnell Aircraft The Garrett Corporation Ohio State University
Training for space crews	Boeing Aircraft The Garrett Corporation The Lovelace Foundation Vought Astronautics (Dallas)

Study Area	Organizations Sponsoring Investigations
Provision for launch-site crews	Pan American World Airways (Atlantic Missile Range)
Communications with space crews	Baylor Medical College Mayo Clinic (Rochester) General Electric Company The Garrett Corporation Southwest Research Institute North American Aviation, Inc. University of Washington
Public domain considerations	University of Maryland
Operational reliability	Vought Astronautics Chance-Vought (Dallas) General Electric American Machine and Foundry Company Minneapolis-Honeywell Electric Boat Division of General Dynamics Corporation The Martin Company Boeing Airplane Company MSA Research Company Firewel Company, Inc. Lockheed Missiles and Space Co. McDonnell AF Corporation The Garrett Corporation
Effects of multiple stressors	Franklin Watts, Inc. Boeing Airplane Company (Seattle) Vought Astronautics

APPENDIX II

The author is indebted to the following organizations whose representatives have provided much of the information presented in this paper:

Aeronutronic—Ford Motor Co.
Aerotch Industries
Airesearch—Garrett Corp.
American Airlines
American Institute for Research
Applied Psychology Corp.
Autonetics—North American
AvCIR—Flight Safety Foundation
AVCO—Research and Adv. Dev., Wilmington, Mass.

Battelle Memorial Institute
Becco Chemical—Food Machinery
Bell Helicopter, Fort Worth
Bell Telephone Laboratories—Murray Hill
Bendix Radio—Baltimore, Md.
Bendix Systems Div. Ann Arbor, Mich.
Boeing Aerospace, Seattle, Wash.
Boeing Airplane Co., Wichita, Kansas
Bolt Beranek and Newman, Inc.
Bostrom Research Laboratories

Collins Radio, Cedar Rapids, Iowa
Convair, San Diego, Calif.
Courtney and Co.

Dynamics Analysis and Control Lab., MIT
Douglas Aircraft, El Segundo, Calif.
Douglas Aircraft, Long Beach, Calif.
Douglas Aircraft, Santa Monica, Calif.
Dunlap and Associates

Eastman Kodak
Educational Research Council
Electro-Technology Magazine

Fairchild Stratos Corp.
Flight Safety Foundation
Ford Motor Co.
Franklin Institute

G.E. Defense Sys. Dept. Syracuse, N.Y.
G.E. Information Sys. Section, Wash. D.C.
G.E. Military Electronics Dept. LMED Ithaca, N.Y.
G.E., Schenectady
Goodyear Aircraft
Grumman Aircraft Engineering Corp.

HRB, Singer Co.
Hughes-Tucson, Fullerton, Culver City, Malibu

IBM Data Systems, Poughkeepsie, N.Y.
IBM Research Center, Yorktown Heights, N.Y.
Information Technology Laboratories
International Electric Corp.

Lear, Inc.
Link, Div. of General Precision
Lockheed Aircraft Corporation, Calif. Company
Lockheed, Georgia Company

Lockheed Missiles and Space Co., Sunnyvale, Palo Alto, Van Nuys, Calif.

Martin Company, Baltimore and Orlando
Mauch Laboratories
McDonnell Aircraft
Melpar, Inc.
M.I.T.
Monsanto Chemical

New York University
North American Aviation, Los Angeles

Philco, Palo Alto and Philadelphia
Psychological Research Assoc. MATRIX Corp.
Purdue University

R.C.A./Defense Electronics
Republic Aviation
Ritchie and Associates

Sierra Engineering
Space Labs, Inc.
Stanford Research Institute
System Development Corp.

Tufts University
Tulane University, Psychology Dept.

U.C.L.A.

Vought Aeronautics

Westgate Laboratory Inc.
Westinghouse Air Arm Division

Visual Estimates of Airplane Speed

ROBERT H. BROWN, U.S. Naval Research Laboratory.

A comparison of field and laboratory studies shows that the variability of visual estimates of airplane speed made by ground observers increases in direct proportion to the mean estimate in the same manner as does the variability of estimates made for quite different moving objects at close range in the laboratory. Since the standard deviation may be used as a measure of sensitivity to differences in speed, it follows that an observer discriminates a constant percentage difference throughout the range of aircraft speeds studied. This rule also seems to be applicable to certain aspects of automobile driving and to tracking of targets on a cathode-ray tube.

Analysis of the accuracy with which observers estimate airplane speed reveals a surprising agreement with the precision of laboratory judgments of velocity and with the way men react to velocity in various situations. Estimates of airplane speed were made by ground observers during World War II in order to determine the potential adequacy of lead angle corrections for antiaircraft machine gun fire. As described by Biel and Brown[1] in a report on an experiment conducted under an NDRC project, twenty Army officers recorded their individual estimates of the speed of airplanes when they were flown on straight-and-level courses which varied in speed, direction, altitude and range.

The most obvious result was the relationship between the mean estimate and the actual speed. On the average, observers increased their estimates with increase in speed, but not proportionately. The tendency to overestimate low speeds and underestimate high speeds has its counterpart in manual responses where individuals overcorrect for small errors and undercorrect for large errors.[6] In addition, Biel and Brown found that the type of plane being flown at the same speed influences estimates, but direction, altitude, and range have no significant effect.

The standard deviations reported for the distributions of estimates are of particular interest. When the standard deviation is plotted against the mean estimate, the relationship is comparable to the direct proportionality found in laboratory studies.[3] In addition, the standard deviation is comparable to determinations of the least discriminable difference in speed ($\Delta\omega$) as discussed by Woodworth and Schlosberg.[8]

The average of the standard deviations of estimates made at a given speed for different planes is plotted in Fig. 1 as a function of the mean estimate. The unit of measurement is the angular speed (ω) in deg./s subtended by the moving airplane at the eye. In converting from the reported linear measurements to angular units, a median range of 2700 ft has been used for an airplane assumed to be moving perpendicular to the line of sight. The straight lines drawn through the experimental points have been derived by the method of least squares.

Results are plotted for estimates made before and after a 4-day training period. The training consisted of informing the observer of the aircraft's true speed immediately after he recorded his estimate. Training lowers the curve uniformly, but does not change the slope of the straight line significantly.

The proportionality apparent in Fig. 1 resembles markedly a similar relationship found by Brown[3] for thresholds measured in the laboratory with such test objects as small black squares pasted on a moving white paper, a moving grid, a moving textured pattern, or a rotating disk. The correspondence suggests that the methods for measuring angular speed developed for use in the laboratory may be extended to field studies of velocity discrimination.

If we assume that $\Delta\omega \propto \sigma_\omega$, then the value of

σ_ω/ω may be compared with measurements of the Weber fraction,[1] $\Delta\omega/\omega$. It is apparent from examination of Fig. 1 that the fraction decreases with training. The trained observers discriminated approximately an 8.5 per cent difference in speed. Highly trained subjects in the laboratory discriminate on the average a 7.7 per cent difference in the speed of two moving objects when they view them alternately.[4]

As may be seen from Fig. 1, an observer discriminates a constant percentage difference in speed over a moderately wide range. This a target on a cathode-ray tube. In the absence of any marked departures from linearity, the relationship is similar to that plotted in Fig. 1 for the visual estimates of airplane speed.

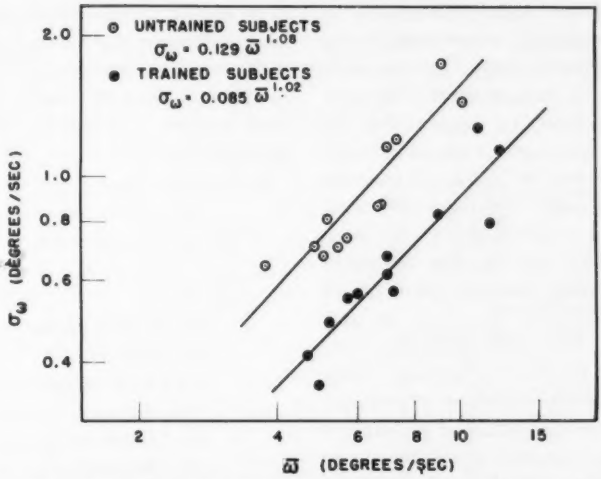

Fig. 1. Variability of the estimates of airplane speed by ground observers as a function of the mean estimate. Points are plotted from the data of Biel and Brown.[1]

notion is a useful concept for various applications. Chandler, Herman, and Montroll,[5] for example, have reported that drivers respond to the relative velocity, rather than distance, of the car ahead. They interpret the "following behavior" of a car in terms of the proportionality of its acceleration to the relative velocity of the car ahead. Likewise, McGuire[7] and Bowen and Chernikoff[2] have reported that tracking error increases with the speed of

[1] Weber's fraction is the ratio of the magnitude of a just noticeable difference in a stimulus to the magnitude of the original stimulus.

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A Component-Type General-Purpose Teaching Machine of Optimum Capability for Curriculum Development

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Each of the teaching machine curriculums developed, so far, embody only one of the several schools of psychological methodology currently known to the practitioner. It is held that machine design *is one factor which acts as a constraint. The general teaching machine environment in terms of a man–machine relationship is defined and ten different modes of the "learner–teaching machine" relationship are delineated. A typical aural–visual teaching machine for curriculum research purposes is graphically described along with information relating to magnetic tape multi-channel assignments and a punched paper tape scoring device.*

Curriculum development practitioners in education and training, when considering teaching machine technology, are presently confronted with a monomorphic decision. Current thinking tends to suggest that the practitioner must embrace one school of lesson plan design for a specific lesson, or even for an entire course of study. This paper, following a pattern earlier established by the non-Euclidian geometries, assumes that *each* teaching point in a teaching machine lesson can be considered *separately* for purposes of item design. It would be entirely possible, using this assumption, to have a teaching point treated as a written-completion or *written* constructed response item popularized by Skinner[1] the following point treated as a multiple-choice response item as originated by Pressey[2] the next designed with a branching mode[4] and the last using oral-completion techniques or *oral* constructed response items similar to those found in language laboratory lessons.[3]

Only two factors act to constrain the curriculum developer: (1) tradition, short-term as it may be, dictates a monomorphic approach; (2) mechanisms or "hardware" at present provide only one mode for man–machine communication. Let us take the position that the objective is learning and it doesn't matter which particular school of lesson plan design is followed so long as it is the best known for each teaching point. Then, only the restrictions of existing hardware remain as a barrier.

In analyzing man–machine communication in a *learning* environment, we observe that there are three major modes of overt response: multiple-choice, oral-completion, and written-completion. Each of these breaks down into a finite number of variations, ten of which are identified below:

A. Multiple-choice:
   (1) Non-branching.
   (2) Branching-review.
B. Oral-completion:
   (1) Echoic.
      (a) Instantaneous.
      (b) Delayed.
      (c) Instantaneous and delayed.
   (2) Discussive.
      (a) Instantaneous.
      (b) Delayed.
      (c) Instantaneous and delayed.
C. Written-completion:
      (1) Demand.
      (2) Timed

The specifications and learner–teaching machine relationships for each of these modes are described and defined in the accompanying diagrams, beginning with the *general* man–machine case.

THE MAN–MACHINE RELATIONSHIP AS DEFINED BY THE TEACHING MACHINE

(1) Machine instructs learner visually *and* aurally, then provides question or problem.

(2) Learner uses instruction to conceptualize answer or solve problem (work; mental–manipulative).
(3) Learner decides upon answer or solution.

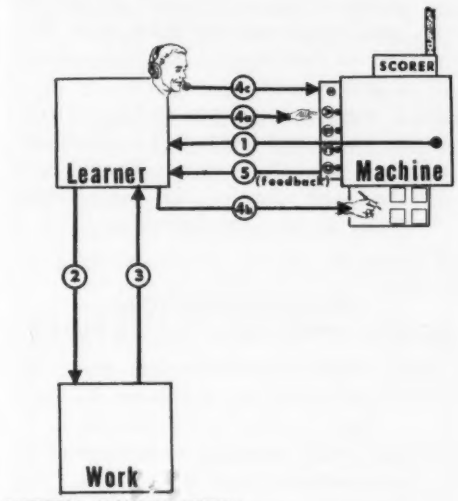


Fig. 1

(4) Learner informs machine by
  (a) multiple-choice,
  (b) written-completion,
  (c) oral-completion.
(5) Machine verifies or has learner verify response and feeds this back to learner. Learner may repeat, branch, or go on to the next incremental instruction depending upon curriculum design.

MULTIPLE-CHOICE NON-BRANCHING MODE

(1) Machine instructs learner visually *and* aurally, then provides question or problem.
(2) Machine automatically illuminates answer buttons A, B, C and D requesting learner to make decision and the aural display *halts*.
(3) Learner uses instruction to conceptualize answer or solve problem.
(4) Learner makes decision.
(5) Learner informs machine of decision by pressing illuminated button A, B, C, or D.
(6a) If response is incorrect, the red light "X" will automatically light and remain lit and the A, B, C and D lights will be automatically extinguished signifying an *incorrect* decision. Learner acknowledges error by touching red light "X" which is then extinguished and button lights A, B, C and D are again automatically illuminated. Learner continues recycle of steps (5) and (6) until correct response (6b) is made.

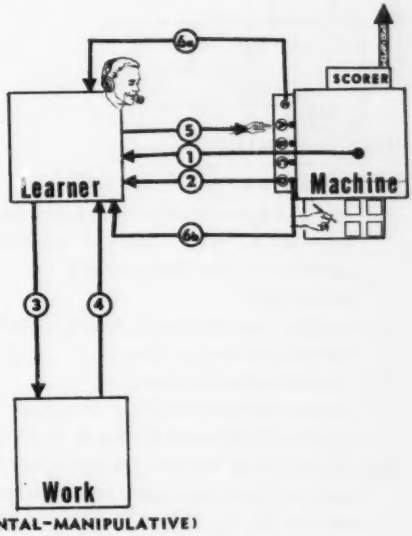
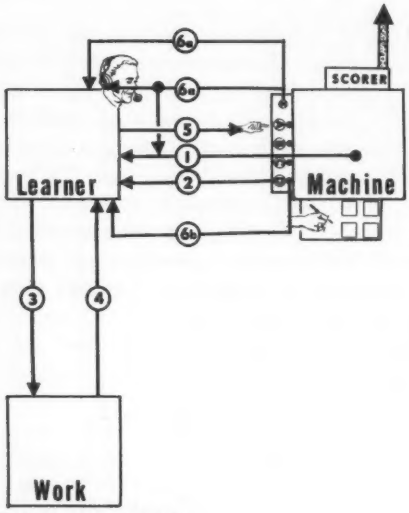


Fig. 2

(6b) If response is *correct*, green light adjacent to the pressed button will automatically light signifying a correct decision, and the aural display will automatically *resume* by providing reinforcing instruction.

MULTIPLE-CHOICE BRANCHING REVIEW MODE

(1) Machine instructs learner visually *and* aurally, then provides question or problem.



(MENTAL-MANIPULATIVE)

Fig. 3

(2) Machine automatically illuminates answer buttons A, B, C and D requesting learner to make decision and the aural display *halts*.

(3) Learner uses instruction to conceptualize answer or solve problem.

(4) Learner makes decision.

(5) Learner informs machine of decision by pressing illuminated button A, B, C or D.

(6a) If response is *incorrect*, the red light "X" will automatically light and remain lit and the A, B, C and D lights will be automatically extinguished signifying an *incorrect* decision. At this moment, the aural display on pre-recorded magnetic tape resumes with an explanation of the *incorrect* decision, providing additional detailed instruction and possibly hints or prompts. The tape automatically halts, rewinds and replays the *original* instruction and the question or problem. Then the learner acknowledges both the error and branched instruction by touching red light "X" which is then extinguished and button lights A, B, C and D are again automatically illuminated. Learner continues recycle of steps (5) and (6) until correct response (6b) is made. For each of three *incorrect* responses, there is a *different* aural explanation.

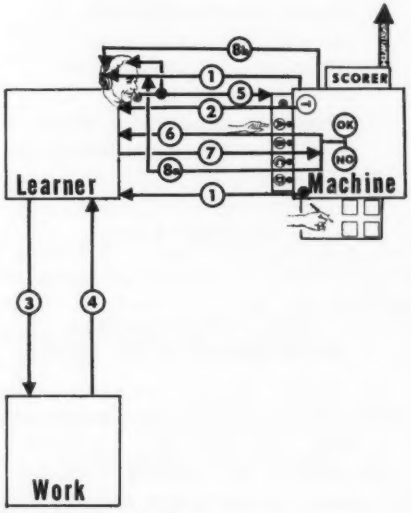
(6b) If response is *correct*, green light adjacent to the pressed button will automatically light signifying a correct decision, and the aural display will automatically *resume* by providing instruction.

ORAL-COMPLETION ECHOIC-INSTANTANEOUS MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screen *and*

(b) Aurally providing a *word or phrase to be echoed.*

(2) Machine automatically illuminates "Talk" light requesting learner to echo orally word or phrase.



(MENTAL-MANIPULATIVE)

Fig. 4

(3) Learner uses instruction to conceptualize response.
(4) Learner completes conceptualization of response within allotted time as indicated by illuminated "Talk" light.
(5) Learner responds orally by talking into microphone and *instantaneously* hears his voice in the headset.
(6) The "Talk" light is automatically extinguished and two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the instruction.
(7) Learner informs machine of decision by pressing illuminated button "OK" or "NO".
(8a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (7) will recycle until a correct or "OK" decision (8b) is made.
(8b) If response is *correct* or "OK", the aural display will automatically resume by providing reinforcing instruction.

ORAL-COMPLETION ECHOIC-DELAYED MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screen *and*
(b) Aurally providing a *word or phrase to be echoed.*
(2) Machine automatically illuminates "Talk" light requesting learner to echo orally word or phrase.
(3) Learner uses instruction to conceptualize response.
(4) Learner completes conceptualization of response within allotted time as indicated by illuminated "Talk" light.
(5) Learner responds orally by talking into microphone.
(6) When "Talk" light is automatically extinguished, the tape automatically rewinds and again aurally displays the instruction in (1b). It then continues with an aural display of the learner's echoic *response* which was recorded for the *delayed* mode.
(7) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the instruction.
(8) Learner informs machine of decision by pressing illuminated button "OK" or "NO".
(9a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (8) will recycle until a correct or "OK" decision (9b) is made.
(9b) If response is *correct* or "OK", the aural display will automatically resume by providing reinforcing instruction.

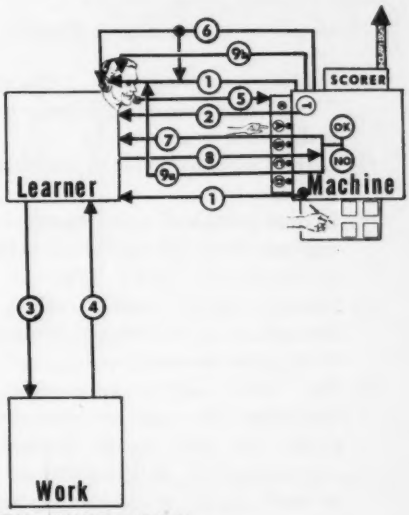


Fig. 5

ORAL-COMPLETION ECHOIC-INSTANTANEOUS AND DELAYED MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screens *and*
(b) Aurally providing a *word or phrase to be echoed.*

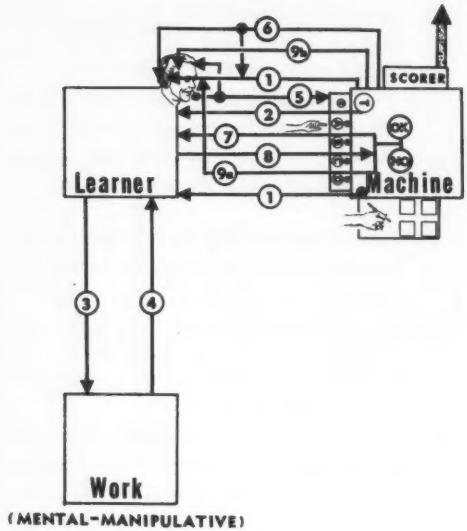


Fig. 6

(2) Machine automatically illuminates "Talk" light requesting learner to echo orally word or phrase.

(3) Learner uses instruction to conceptualize response.

(4) Learner completes conceptualization of response within allotted time as indicated by illuminated "Talk" light.

(5) Learner responds orally by talking into microphone and *instantaneously* hears his voice in the headset.

(6) The "Talk" light is automatically extinguished, the tape automatically rewinds and again aurally displays the *instruction* in (1b). It then continues with an aural display of the learner's echoic *response* which was recorded for the *delayed* mode.

(7) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the instruction.

(8) Learner informs machine of decision by pressing illuminated button "OK" or "NO".

(9a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (8) will recycle until a correct or "OK" decision (9b) is made.

(9b) If response is *correct* or "OK", the aural display will automatically resume by providing reinforcing instruction.

ORAL-COMPLETION DISCUSSIVE-INSTANTANEOUS MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screen *and*

(b) Aurally *presenting a question* or *making a statement* which should elicit a shaped oral response.

(2) Machine automatically illuminates "Talk" light requesting learner to respond orally with an *answer* or *statement*.

(3) Learner uses instruction to conceptualize response.

(4) Learner completes conceptualization of response within allotted time as indicated by illuminated "Talk" light.

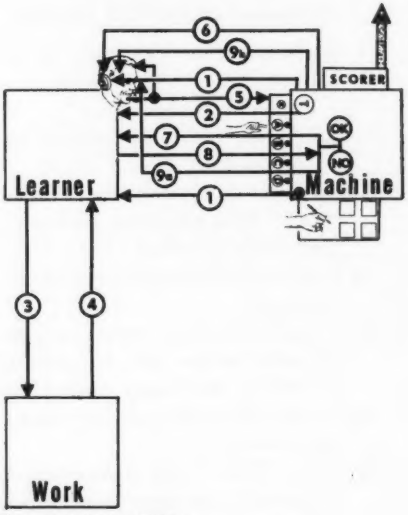


Fig. 7

(5) Learner responds orally by talking into microphone and *instantaneously* hears his voice in the headset.

(6) When "Talk" light is automatically extinguished, learner hears the *instructor's response* in the form of an answer or statement.

(7) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the instructor's idealized version.

(8) Learner informs machine of decision by pressing illuminated button "OK" or "NO".

(9a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (8) will recycle until a correct or "OK" decision (9b) is made.

(9b) If response is *correct* or "OK", the aural display will automatically resume by providing reinforcing instruction.

ORAL-COMPLETION DISCUSSIVE-DELAYED MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screen *and*

(b) Aurally *presenting a question* or *making a statement* which should elicit a shaped oral response.

(2) Machine automatically illuminates "Talk" light requesting learner to respond orally with an *answer* or *statement*.

(3) Learner uses instruction to conceptualize response.

(4) Learner completes conceptualization of response within allotted time as indicated by illuminated "Talk" light.

(5) Learner responds orally by talking into microphone.

(6) When "Talk" light is automatically extinguished, learner hears the *instructor's response* in the form of an answer or statement.

(7) The tape then automatically rewinds and provides aural display in this sequence:

(a) step (1b)—pre-recorded question or statement by *instructor*,

(b) step (5)—oral response by *learner*,

(c) step (6)—pre-recorded idealized response by *instructor*.

(8) Two grading buttons "OK" and "NO" are illuminated, requesting learner to make a decision regarding the quality of his response compared with the instructor's idealized version.

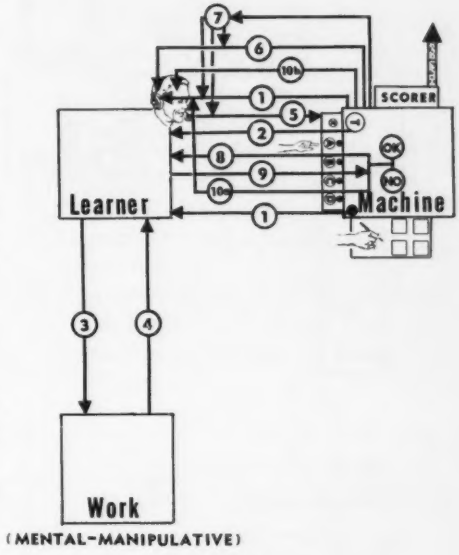


Fig. 8

(9) Learner informs machine of decision by pressing illuminated button "OK" or "NO".

(10a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (9) will recycle until a correct or "OK" decision (10b) is made.

(10b) If response is *correct* or "OK", the aural display will automatically resume by providing reinforcing instruction.

ORAL-COMPLETION DISCUSSIVE-INSTANTANEOUS AND DELAYED MODE

(1) (a) Machine instructs learner visually by presenting text or picture on screen *and*

(b) Aurally *presenting a question* or *making a statement* which should elicit a shaped oral response.

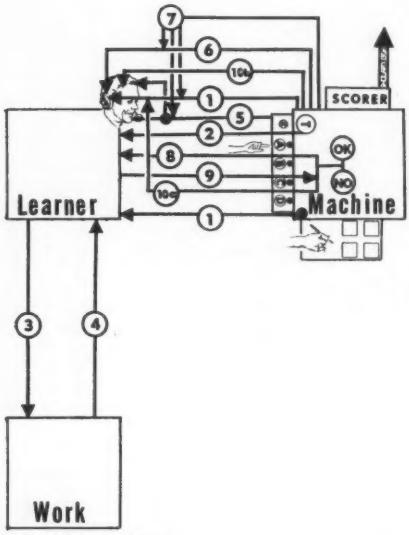


Fig. 9

(2) Machine automatically illuminates "Talk" light requesting learner to respond orally with an *answer* or *statement*.

(3) Learner uses instruction to conceptualize response.

(4) Learner completes conceptualization of response within allotted times as indicated by illuminated "Talk" light.

(5) Learner responds orally by talking into microphone and *instantaneously* hears his voice in the headset.

(6) When "Talk" light is automatically extinguished, learner hears the *instructor's response* in the form of an answer or statement.

(7) The tape then automatically rewinds and provides aural display in this sequence:
(a) step (1b)—pre-recorded question or statement by *instructor,*
(b) step (5)—oral response by *learner*,
(c) step (6)—pre-recorded idealized response by *instructor.*

(8) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the instructor's idealized version.

(9) Learner informs machine of decision by pressing illuminated button "OK" o "NO".

(10a) If response is *incorrect* or "NO", the tape will automatically rewind and steps (1) to (9) will recycle until a correct or "OK" decision (10b) is made.

(10b) If response is *correct* or "OK", the aura display will automatically resume by providing reinforcing instruction.

WRITTEN-COMPLETION DEMAND MODE

(1) Machine instructs learner visually and aurally, then provides question or problem.

(2) Machine automatically illuminates "Write" button requesting learner manually to write word or phrase or to solve problem and manually to write solution.

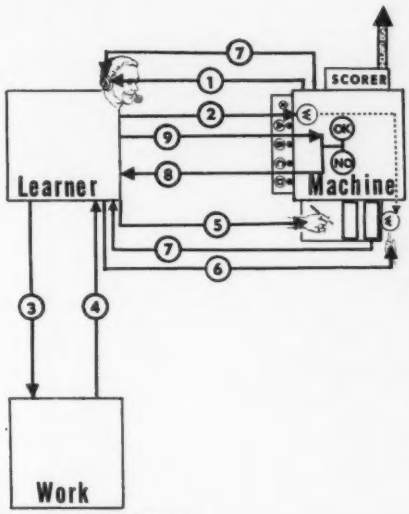
(3) Learner uses instruction to conceptualize response or solve problem.

(4) Learner completes conceptualization or solution. In the *demand* mode, there is no time limit—the learner will call for or "demand" the next step.

(5) Learner writes answer into machine.

(6) Learner presses the "Write" button manually which is then extinguished.

(7) Paper moves under a transparent viewing plate visually displaying the learner's



(MENTAL-MANIPULATIVE)

Fig. 10

written response, and the tape resumes with an aural display of the correct answer or answers. A change in visual screen display may also provide correct answers.

(8) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the machine's correct version.

(9) Whether "OK" or "NO", the aural and visual display will provide reinforcing instruction and continue on to the next teaching point.

WRITTEN-COMPLETION TIMED MODE

(1) Machine instructs learner visually and aurally, then provides question or problem.

(2) Machine automatically illuminates "Write" button requesting learner manually to write word or phrase or to solve problem and to manually write solution.

(3) Learner uses instruction to conceptualize response or solve problem.

(4) Learner completes conceptualization or solution. In the *timed* mode, there is a time limit measured in minutes or seconds—the learner is required to respond and if he does not, the next step is automatically taken.

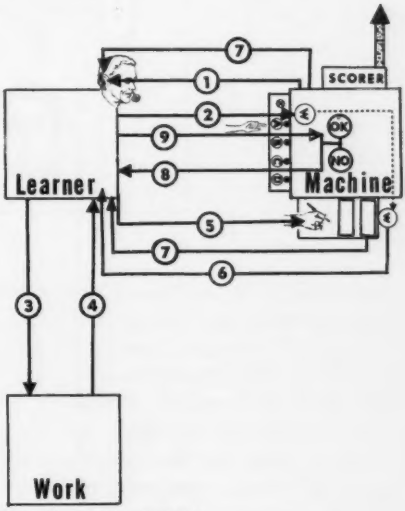
(5) Learner writes answer into machine.

(6) At the end of the allocated response time, the "Write" button is automatically extinguished.

(7) Paper moves under a transparent viewing plate visually displaying the learner's written response, and the tape resumes with an aural display of the correct answer or answers. A change in visual screen display may also provide correct answers.

(8) Two grading buttons "OK" and "NO" are illuminated requesting learner to make a decision regarding the quality of his response compared with the machine's correct version.

(9) Whether "OK" or "NO", the aural and visual display will provide reinforcing instruction and continue on to the next teaching point.



(MENTAL-MANIPULATIVE)

Fig. 11

It is generally agreed that the teaching machine viewed as a mechanism is like a television receiver mechanism—unless local television channels are operative, man isn't communicating with the machine. The man–machine relationship would consist primarily of man applying a dust cloth to the machine periodically. The teaching machine mechanism requires lesson plans (inappropriately termed "programs" by some) just as the television mechanism requires programming. Only then will a true man–machine relationship develop in terms of communication.

Having observed ten modes of overt response to validate this communications relationship, we may briefly turn to the general *modus operandi* for the physical production of lesson plan materials. In this teaching machine 35 mm standard color slides, standard quarter-inch magnetic tapes, blank paper scrolls, and blank five-channel standard teleprinter paper tape constitute these materials. The scrolls and paper tape are expendable supplies.

The flow chart in Fig. 12 describes the curriculum development continuum from inception of lesson planning through materials production to utilization, criterion testing, performance evaluation and feedback for lesson plan improvement. The teaching machine is shown in Fig. 13.

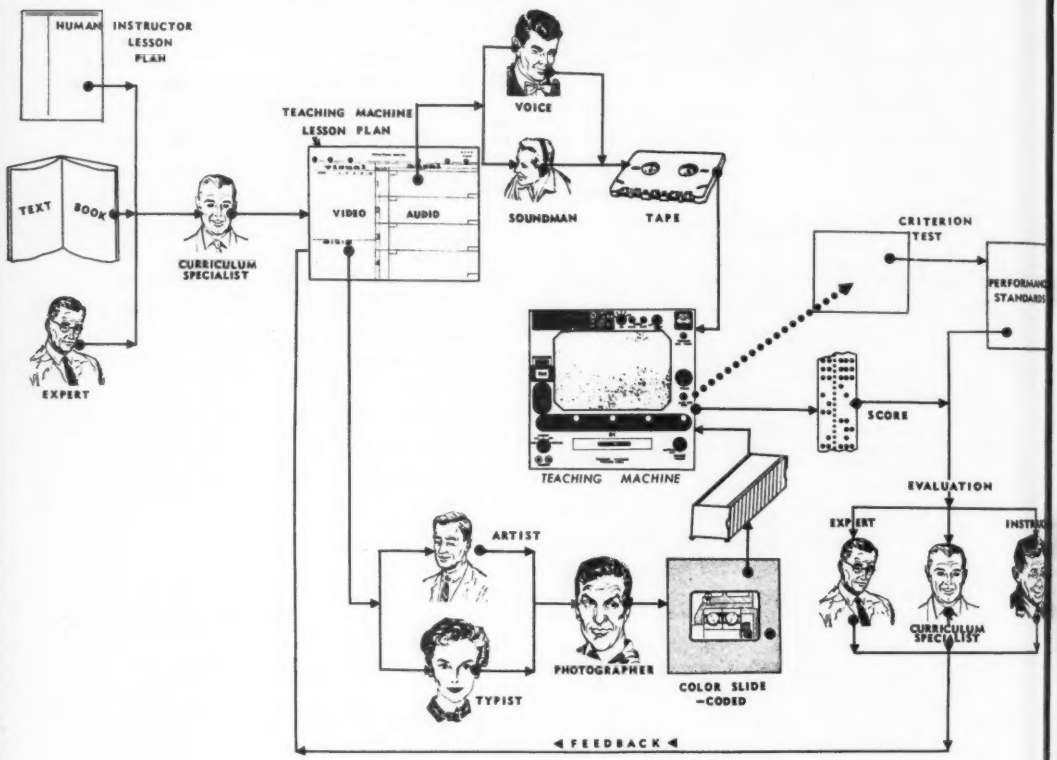
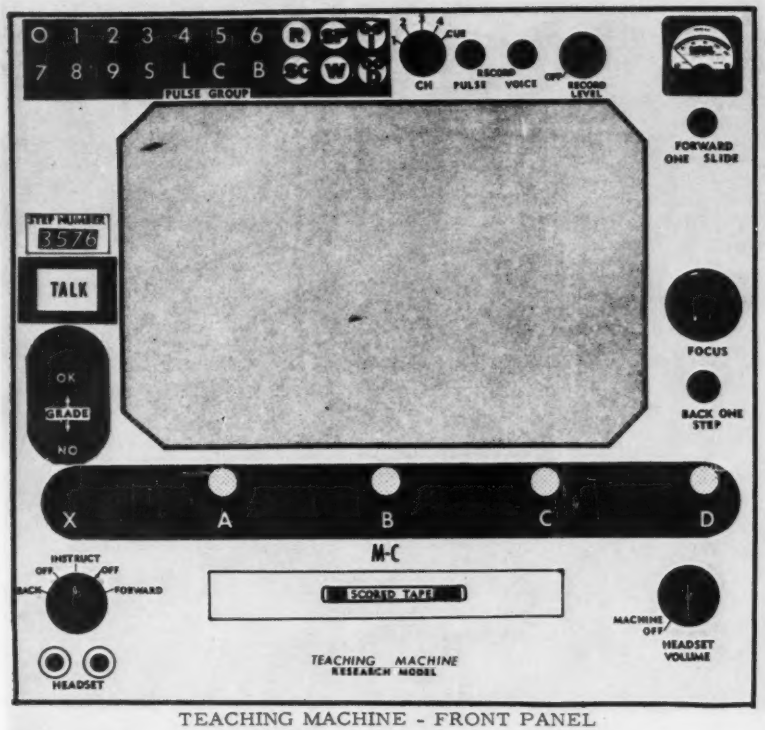
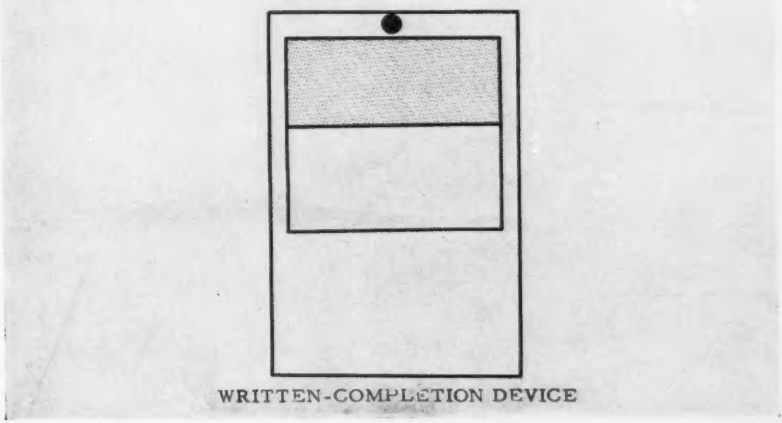


Fig. 12

To provide fully-automatic and learner-initiated machine actions, subsonic sound pulses are stored on various channels of standard quarter-inch magnetic tape. The



TEACHING MACHINE - FRONT PANEL



WRITTEN-COMPLETION DEVICE

Fig. 13

MAGNETIC TAPE CHANNEL ASSIGNMENTS

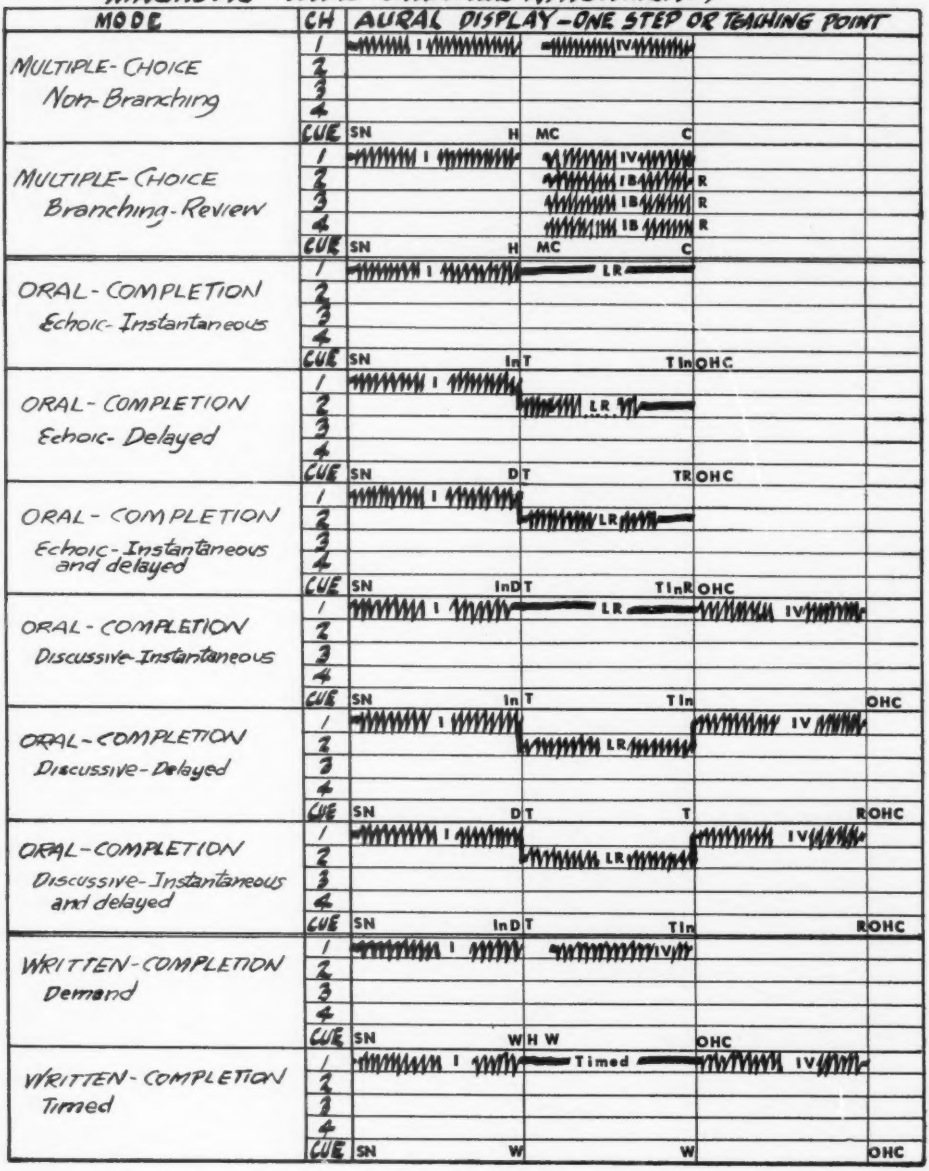


Fig. 14

channel assignments are shown in Fig. 14. It is seen that the modes correspond with those presented previously. The "CH" or channel column consists of four voice and one cueing channel. Automatic functions are controlled by pulses on the cueing or voice channels and semi-automatic functions by switch insertions performed by the learner. The cues are:

Legend

I = Aural instructor display, pre-recorded,

R = Automatic tape rewind-recycle; at end of recycle continues on to next cue,

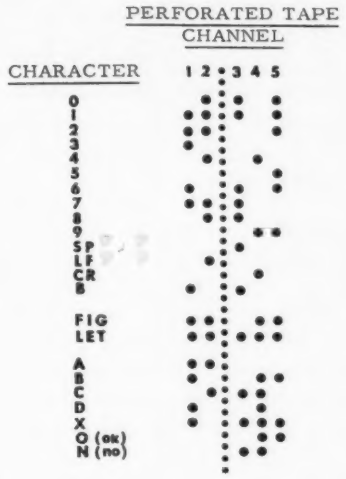
MC = Multiple-choice response-tape starts,

SN = Step number; a teaching point consists of steps,

C = Automatic slide change,

T = Automatic "Talk" light; first T = on, second T = off,

O = "OK"–"NO" buttons automatically lighted and energized; rewind when "NO" is pressed,



SP = Space
LF = Line Feed
CR = Carriage Return
B = Bell

CR occurs on page printers and , on tape printers
LF occurs on page printers and . on tape printers

Fig. 15

LR = Oral learner response,

In = Aural display of LR (oral learner response) in instantaneous mode, played through headset; first In = on, second In = off,

D = Aural display of LR (oral learner response) in delayed mode, recorded on tape and played later through headset,

IV = Instructor version of *ideal* answer; pre-recorded,

IB = Instructor explanation of *incorrect* answer; pre-recorded,

H = Automatic tape halt,

W = "Write" button automatically lighted and energized; first W = on, second W = off.

Each time the learner responds to a stimulus with a switch insertion, the nature of the response is recorded on standard teleprinter five-channel paper tape. For example, while the learner is aurally and visually receiving instruction on teaching point 29, pulses on the *magnetic* tape will activate FIG—2, 9. If the response is in one of the multiple-choice modes, the learner is to press button A, B, C or D. When the *correct* response is made, the

manual switch insertion by the learner will also punch the letter on the paper tape as "LET", C. If the correct answer is C, but D is pressed, then the paper tape will be perforated as "LET", D, X. Of course, step (6a) in the man–machine diagrams for multiple-choice modes will be initiated. If the response is in one of the six oral-completion modes, the learner presses the the grading buttons "OK" or "NO". The manual switch insertion will cause either "LET", O or "LET", N to punch; the same will occur in the two written-completion modes. For those investigators who plan to have the perforated tape print out the data on tape or page *printers*, space, line feed, carriage return and bell characters may be pre-recorded as pulses on the magnetic tape in the same manner as prerecorded numerals for the teaching point numbers shown in Fig. 15.

In this manner, item analyses and individual learner response patterns may be studied leisurely after the learners have completed a lesson.

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Dr. Adams received his Ph.D in experimental psychology from the State University of Iowa in 1951, and joined the Perceptual and Motor Skills Laboratory, USAF Human Resources Research Center, where he performed a number of laboratory experiments on fatigue processes, vigilance, individual differences in learning, and problem solving. In 1954 he moved to the Interceptor Pilot Research Laboratory, USA Air Force Personnel and Training Research Center, and conducted research on training problems of pilots and radar observers of all-weather interceptor aircraft of the Air Defense Command. Much of this research used electronic flight simulators as research instruments. Other research projects at the Interceptor Pilot Research Laboratory were on training and proficiency measurement problems for the GCI radar operators of the Air Defense Command, and human factors variables in the operational suitability testing of new air weapons. Dr. Adams joined the faculty of the University of Illinois in 1957.

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Dr. Brown is editor of *Illumination and Visibility of Radar and Sonar Displays,* National Academy of Sciences—National Research Council (1958). A fellow of the American Psychological Association, he is also a member of Eastern Psychological Association, Optical Society of America, Psychonomics Society, Phi Beta Kappa, and Sigma Xi. Dr. Brown has contributed to the literature on perceptual and display problems in various publications of journals, government laboratories, and universities.

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He has been responsible for the human factors psychologists working on the B-70, Apollo and TFX programs. Prior to joining North American, he was a research fellow at Purdue University, where he received his Ph.D. in 1960. He also spent four years as a jet fighter pilot with the USAF, and a short period in 1954 as a job analyst with Collins Radio Company.

LEE W. GREGG and RICHARD G. PEARSON (*Factorial Structure of Impact and Damage Variables in Lightplane Accidents*)

LEE W. GREGG is a professor of psychology at Carnegie Institute of Technology in Pittsburgh, Pennsylvania. After receiving his B.S. at Northwestern University in 1948, he went to the University of Wisconsin where he received the M.S. (1950) and Ph.D. (1952) in psychology with a minor in electrical engineering. His interest in the human factors field began at Wisconsin as a result of his assistantship work under Air Force contracts.

Since 1952 his teaching and research at Carnegie have been concerned with a variety of problems related to human performance capabilities. As principal investigator, he conducted investigations that attempted to use muscle action potentials as indices of motor performance and fatigue for the U.S. Army Quartermaster Research and Development Command. This work was later supported by the National Science Foundation. As co-principal investigator with Dr. Harry W. Karn under a continuing contract with the U.S. Air Force Office at Scientific Research, he is engaged in studies of perceptual learning and performance. Under a current grant from the Carnegie Corporation, work in the computer space simulation of cognitive processes in perceptual performance and problem solving is being carried

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Dr. Gregg is the author of approximately twenty-five research papers and has contributed a chapter, "Engineering Psychology", to the recently published *Industrial Psychology* by Dr. B. von Haller Gilmer. He is a member of the American Psychological Association, Midwestern Psychological Association, Psychonomics Society, and the Society of the Sigma Xi.

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After receiving his master's degree in industrial psychology from Purdue University in 1953, he entered the Air Force and was assigned to the School of Aviation Medicine at Randolph Field, Texas. There he conducted research in the areas of fatigue and work decrement, the effects of drugs upon perceptual and motor skills, and visual and proprioceptive perception of verticality. He also participated in an evaluation for the Military Air Transport Service of fatigue factors in long-range flights. His doctoral training in experimental psychology was taken from 1957 to 1960 at Carnegie Institute of Technology, where he taught introductory psychology. His association with the Flight Safety Foundation began with his participation, during the summer of 1958, in a study of environmental factors affecting the proficiency of air traffic control personnel. He is a member of the American Psychological Association, Midwestern Psychological Association, Aerospace Medical Association, and the Human Factors Society.

DAVID MEISTER (*The Measurement of Man–Machine Systems Under Field Operational Conditions*) is head of the Human Requirements Group in the Reliability Control Engineering Dept. of General Dynamics-Astronautics. He received his Ph.D. in experimental psychology from the University of Kansas in 1951 and joined the U.S. Navy Electronics Laboratory in San Diego, California, where he specialized in studies of underwater sound discrimination and evaluations of prototype sonar equipment. In 1955 he accepted a position with the American Institute for Research in Pittsburgh, Pennsylvania, as Assistant Project Engineer working on problems of maintenance of ground equipment. Dr. Meister has been with GD/A since January of 1956 where his group has been responsible for the human engineering of the Atlas, Centaur and other space vehicle systems. He is a member of the American Psychological Association and Sigma Xi. He is author of numerous papers on the relationship between human engineering and reliability problems and was largely responsible for developing the Personnel Sub-system Test Plan presently being implemented at GD/A's Operational Systems Test Facility, Vandenberg Air Force Base. He is presently writing a manual of procedure for human factors field testing.

LEONARD G. SILVERN (*A Component-Type General-Purpose Teaching Machine of Optimum Capability for Curriculum Development*) is Education and Training Research Director for Videosonic Systems at the Hughes Aircraft Company at Culver City, California. In this position, he is responsible for all teaching machine design and curriculum development efforts in both commercial and military fields. Dr. Silvern served in the U.S. Navy and was stationed at the Naval Research Laboratory, Anacostia, Washington, D.C., and with fleet combat units in the Pacific from 1944 to 1946. He studied engineering at the City College, College of the City of New York, later receiving the B.S. degree in physics from the Long Island University, and the M.A. and Ed.D. degrees in technical education from Columbia University in 1948 and 1952 respectively. Concurrently

while obtaining his undergraduate education, he completed a four-year apprenticeship as machinist-toolmaker. From 1939 to 1949, he was Training Supervisor for the Production Branch, Navy Department, N.Y. Naval Shipyard. In 1949, he associated with the Executive Department, State of New York, as Training Director for the Division of Safety in Albany, N.Y. In addition to his training duties, he was a co-contributor to the design of the statewide two-way radio communications network for the fire service and was also State Deputy Radio Officer in the Civil Defense Commission. He remained until 1955 when he joined the Rand Corporation as behavioral scientist assigned to represent the company at M.I.T. Lincoln Laboratory, Lexington, Massachusetts. While with Rand, he was concerned with training and learning problems dealing with AN/FSQ-7 SAGE digital computers and computer programming. In 1956, he affiliated with the Hughes Aircraft Company as Head of Technical Training Program Evaluation and Development in the Field Engineering Department and was engaged in curriculum and performance test development in E-9, MG-3, MG-10 and MA-1 Weapons Systems for maintenance purposes. In 1958, he became Assistant Head of Advanced Scientific Education, General Offices, and in 1959 was appointed Head of Educational Program Co-ordination in the corporate office of the Vice-President of Engineering. He was responsible for the Howard Hughes Doctoral Fellowship Program, Staff Doctorial Fellowship Program, Master's Fellowship Program and others dealing with institution–company relations. He is also on the faculty of the Graduate School, University of Southern California.

Dr. Silvern is a member of the American Psychological Association, American Society for Engineering Education, Society of Engineering Psychologists, National Society for the Study of Education, American Society of Training Directors, and the Association for Computing Machinery. His papers have appeared in *IRE Transactions in Human Factors in Electronics, Personnel Journal, Home Study Review, Journal of the American Society of Training Directors, Fire Engineering,* and others.

Editorial

INFORMATION MISERS: EVOLVING ETHICS IN SCIENCE AND PROFESSION

A major and essentially uncontested precept of both science and profession is the notion that information and theory must be shared and evaluated by the science. This precept is ordinarily reflected in the sense of obligation of the members of the profession to share promptly research findings and applications with their colleagues. In recent years, some circumstances have operated to facilitate intra-scientific communication. However, one particular circumstance threatens to produce an extremely significant net deficit in such scientific communications.

I believe this circumstance is related to the infiltration of a dangerous ethic among scientific and professional personnel in this country. My possibly myopic perceptions lead me to believe that scientists and professionals in increasingly substantial numbers are permitting a variety of factors to narcotize their scientific conscience. The resulting somnolence prevents them from expending the necessary efforts required for preparing and disseminating communications regarding their scientific and professional activity.

The uncomplicated symptomatology of this disease process is characterized by paradoxical signs. One is that the affected person places great value and exerts considerable energy in demanding and getting from his colleagues every bit of available scientific written and oral information. Simultaneously, he returns little or no scientific information. Those afflicted with this disease are not unaware of their pathology. They even offer "validated etiologies" in explanation. These include: "too much other high priority work", "completion of a piece of research or application causes me to lose interest and I have no motivation to write it up", "my company considers the results of my work to be proprietary information", "my work is related to the national defense and is classified at so high a level that I can't even think about it", etc.

Even if the proposed etiologies are ultimately demonstrated to be true, it seems inconceivable that serious and committed scientists and professionals could tolerate for a single moment any delay in seeking out and testing various symptomatic treatments. Such tentative treatments might include: "individual resolution and commitment to write up the data from those several studies done last year", "the exploration with corporate management for more frequent and systematic release of company classified research and application", "the extraction of security information from reports in their preparation", "the establishment of more frequent declassification procedures and reviews", etc. It is suspected that a high degree of success would be encountered in the application of such symptomatic therapy. However, the most appropriate response to the increasing epidemic character of this disease process would be a campaign involving preventative inoculation. This inoculation, administered by the Society, would involve the recognition and ethical reaffirmation that the science and the profession must receive prime loyalty in the dissemination of research findings and applications. Without it, the science cannot progress satisfactorily. It is particularly true in this day and age of increasing social and technical complexity and interaction, that in the human factors area we need to do everything possible to facilitate information transfer to *all* concerned.

It is readily acknowledged that we already have a number of obstacles to communication in the form of limited numbers of journals, large numbers of published works to read, etc., and that were additional increments of material to be published, the available communication networks might become clogged. I submit that this is substantially nothing more than rationalization for the lack of current efforts in regard to published dissemination of scientific

information. The unfortunate fact today is that very few, if any, individuals in the profession are as knowledgeable about the work of others as they should be, and the self-inhibiting quality that is discussed above represents one of the most serious factors contributing to this lack of individual sophistication. Though I appreciate the significant role that scientific conferences and private communications have for the science as a whole, it is erroneous to interpret the above ethic other than in the context of written published communications. Therefore, it is extremely important that an infant science and profession such as ours affirm and reinforce at a very early date an ethic which is applicable to every individual member of that profession regarding the preparation and dissemination of information.

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